中美大豆

Soybean Research in China and the United States

Proceedings of the First China/USA Soybean Symposium and Working Group Meeting

UNITED STATES DEPARTMENT OF AGRICULTURE,
OFFICE OF INTERNATIONAL COOPERATION AND DEVELOPMENT

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ANIMAL HUSBANDRY, AND FISHERY

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN,
COLLEGE OF AGRICULTURE

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Proceedings of the First China/USA Soybean Symposium and Working Group Meeting

July 26 to 30, 1982
University of Illinois at Urbana-Champaign
Urbana, Illinois USA

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James B. Sinclair, and Wang Jin-ling

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Foreword

The International Soybean Program (INTSOY) is seeking to improve human nutrition and economic development around the world through the increased use of soybeans. Cooperating with like-minded national and international organizations, we work toward this goal in a number of ways. In cooperation with local, regional, and international organizations, INTSOY sponsors or collaborates in conferences that explore major research and technological problems in soybean production, processing, marketing, and use. These conferences have stimulated interest in the use of soybeans as a food source and enlarged the body of knowledge available to soybean researchers, educators, producers, and consumers.

These proceedings of the First China/USA Soybean Symposium and Working Group Meeting provide the first comprehensive and formal presentation of the past and present research and development activities on soybeans in China, the soybean's center of origin. Likewise, the proceedings present a summary of U.S. soybean research and development which led to the U.S. becoming the world's largest producer and consumer of soybeans. We hope that this compilation will bring perspective to the work that has been done both in the U.S. and China and insight into the development of future collaborative projects in both countries.

INTSOY expresses appreciation to persons recognized in the preface, to the participants in the conference, and to the members of the various committees who contributed to the success of the conference. The Chinese Ministry of Agriculture, Animal Husbandry, and Fishery, and the United States Department of Agriculture are to be thanked for their foresight in funding the conference. I wish to express my appreciation to the editors, J. B. Sinclair, B. J. Irwin, and Wang Jin-ling, for their efficient and dedicated efforts in preparing this volume.

H. E. Kauffman
INTSOY Director

Preface

The China/USA Soybean Symposium and Working Group Meeting was held at the University of Illinois at Urbana-Champaign from July 26 to 30, 1982. This meeting was sponsored and supported by the College of Agriculture, University of Illinois at Urbana-Champaign, and the Office of International Cooperation and Development (OICD) of the United States Department of Agriculture (USDA) through arrangements developed by the International Science and Education Council. This historic occasion marked the first academic symposium supported by the China Program in USDA/OICD. The major objectives of the symposium were to:

1. Better understand the development and current status of the soybean sectors in the People's Republic of China and the U.S.; and
2. Develop cooperative scientific programs which would benefit consumers and producers of soybeans in both countries.

This China/USA Soybean Symposium and Working Group Meeting represented the next logical step in evolving scientific and technical exchange programs in soybeans between China and the U.S. Previous agricultural scientific and technical exchange efforts were oriented to providing, in a short time period, an opportunity for Chinese and American scientists to become acquainted with a variety of institutions and with scientific colleagues in both countries. This symposium and working group meeting was designed to provide, over a longer period of time, an opportunity for soybean workers of both countries to share general information with a wider audience, interact on current efforts and problems within smaller groups, and become acquainted with each other so that collaborative and mutually beneficial work could be planned and developed.

Planning for the symposium and workshop was carried out jointly in both China and the U.S. with contacts being made through a liaison secretary in each country; Huang Yong-nin for the People's Republic of China, and Thomas F. Kelly for the U.S. Department of Agriculture. The program was divided into three parts: the general symposium to which the general public was invited, the scientific working group meetings for soybean scientists, and field experiences. Seven soybean scientists came from the People's Republic of China and were joined by a number of Chinese soybean scientists who were studying in the U.S. Over thirty U.S. scientists were invited to participate in the symposium and working group sessions. These sessions involved a small number of Chinese and U.S. scientists focusing on specific areas of interest in soybean production and utilization. Following these meetings, the Chinese delegation spent 15 days visiting public and private institutions in the U.S. soybean industry.

The planning committee, using suggestions for format and topics proposed by Chinese and U.S. personnel, included the following people.

Chairman: H. E. Kauffman, Director, INTSOY, UIUC.

Members: R. L. Bernard, USDA, ARS, Urbana; R. E. Ford, Department of Plant Pathology, UIUC; R. M. Goodman, Department of Plant Pathology and INTSOY, UIUC; R. W. Howell, Department of Agronomy, UIUC; R. W. Judd, National Soybean Crop Improvement Council, Urbana; M. Kogan, Department of Agricultural Entomology and INTSOY, UIUC; G. E. Pepper, Department of Agronomy, UIUC; C. M. Pribble, Office of International Agriculture, UIUC; A. J. Siedler, Department of Food Science, UIUC; and J. B. Sinclair, Department of Plant Pathology and INTSOY, UIUC.

More than 200 people participated in the symposium, including representatives from the public and private sectors. U.S. representatives were present from: the colleges of agriculture of soybean producing states; midwest soybean processing firms; soybean seed companies; agribusiness corporations; national and state agricultural organizations; the USDA; state legislatures; and the College of Agriculture's advisory committees. Chinese representatives came from: agricultural colleges; the Ministry of Agriculture, Animal Husbandry, and Fisheries; Chinese Embassy; provincial academies of agricultural sciences; and the Chinese

Academy of Agricultural Sciences. Besides China, delegates came from Arkansas, California, the District of Columbia, Florida, Illinois, Indiana, Iowa, Louisiana, Michigan, Minnesota, Mississippi, Missouri, New Jersey, New York, Ohio, Pennsylvania, Texas, Utah, and Wisconsin. The Asian Vegetable Research and Development Center (AVRDC) was represented.

An ad hoc committee consisting of Chinese and UIUC members met to establish guidelines for the editing and publishing of these proceedings. The members of the committee from China were: Wang Jin-ling, editor; Qu Ning-kang, Shen Jin-pu, and Yang Hong; and from UIUC were: J. B. Sinclair, editor; B. J. Irwin, editor; E. D. Kellogg, and H. E. Kauffman. This English edition is one in a series of publications of UIUC's INTSOY program and has been used for translation into a Chinese edition.

The contributions of all who assisted in conceptualizing, planning, and implementing this important event are gratefully recognized. While this publication represents a milestone in soybean scientific cooperation between two of the world's largest soybean producing nations, much remains to be done before the benefits of scientific and technical exchange can be fully realized.

Earl D. Kellogg
Program Leader
China/USA Soybean Symposium
and Associate Director
International Agriculture
UIUC

Inaugural Addresses

Greetings, College of Agriculture

ORVILLE G. BENTLEY

It is an honor to be the moderator of the opening session of the China/USA Soybean Symposium and Working Group Meeting. I extend a cordial welcome to the distinguished scholars from the People's Republic of China and to our U.S. colleagues.

This is a unique seminar. Obviously its focus is on soybean production and utilization, but there is a distinct international dimension to these meetings. They provide the opportunity to further a stated goal of our two governments, that is, to encourage scientific interchange in the area of food and agriculture between representatives of our two countries.

Soybeans are an ancient crop in China and in many ways a relatively new one for the U.S. There has been a long history of exchanges of germplasm and information on technical and scientific issues, and thus it is fitting that this tradition be continued in our common effort to improve soybean production and to expand the utilization of edible oil and high-quality protein derived from this crop.

There have been a number of scientific exchanges between the U.S. and China beginning in the early 1970's, reflecting our agreement that the exchange of information on food and agriculture provides a means for increasing food production as well as building international understanding. These discussions also reflect the recognition of a concern for the importance of food to our national interests and more broadly for peace and security worldwide.

Implicit in developing this seminar program is the understanding that through these discussions both U.S. and Chinese scientists will have the opportunity to explore areas for collaboration and cooperative effort. To this end the seminar program provides for visits to specialized laboratories both in industry and government, farm tours, and visits to private sector processing and marketing firms throughout the country. The first phase of the seminar begins here at the University of Illinois at Urbana-Champaign, but the program involves scientists from other U.S. universities, various research agencies of the Agricultural Research Service of the U.S. Department of Agriculture, industrial laboratories, and private consultants.

O. G. Bentley is Dean of the College of Agriculture, UIUC.

Greetings, U.S. Department of Agriculture

DAVID M. DAUGHERTY

On behalf of U.S. Secretary of Agriculture John R. Block, I would like to extend greetings and a special welcome to our Chinese guests, and to relate his deep appreciation to the University of Illinois at Urbana-Champaign and private sector hosts who have worked together in arranging this symposium and post-conference travel.

The U.S. Department of Agriculture is very pleased with the cooperation that has developed with the People's Republic of China under our agricultural accord. This relationship is coordinated through our Office of International Cooperation and Development.

Activities generated under this agreement include scientific exchanges, cooperative research, training, and university linkages. Our agreement has served as a facilitating vehicle for our cooperators and private interests as well. It is important to note that since our agreement was signed, more than 400 U.S. and Chinese scientists have participated in these exchanges.

The benefits of the exchanges are already evident in the free transfer of information and scientific work on pests, germplasm, and economic information, and in the growth of our agricultural trade. We are partners in this program, and the activities formulated by both sides in respective agricultural and farm community circles address these common interests on a cost-sharing basis.

It is appropriate that our two countries should be working together on soybeans and meeting together in Illinois. The People's Republic of China is the origin of this important crop plant and the U.S. is the largest producer. The topical areas of the symposium, ranging from genetics to the development of soy products, show the common interests of both countries. For example, increases in soybean yields through improved breeding and plant protection strategies will help to improve the economic well-being of our farm communities.

Both countries benefit in this and other exchange programs. We have learned from previous visits to China that soybean research is increasing very rapidly. We believe the sharing of knowledge by Chinese and American scientists visiting laboratories and research centers in the universities will lead to significantly increased soybean production and add substantially to research knowledge of soybean utilization.

These goals can be achieved from a broad mix of scientific, university, business, and government talents of both sides. It is a good sign when all sectors express an interest in a program such as this one. The linking of such knowledge, resources, and talent can only lead to better understanding and progress. I am pleased that this symposium will be followed by a joint symposium to be held in China in 1983.

The U.S. Department of Agriculture's long-range program of activities with the People's Republic of China will be reviewed and discussed at the fourth Joint Working Group on Agricultural Cooperation meeting to be held in Washington, D.C., in 1982. At the joint session both sides will focus again on the results of our programs and on the new projects planned for the coming year. We have found a deep-seated interest by the farm community in pursuing further activities and joint endeavors that strengthen our relationships with China and lead to stronger commercial ties.

The U.S. Department of Agriculture favors efforts to promote international cooperation through government-to-government agreements. We look forward to working even more closely with the universities and the business sector in developing joint strategies for utilizing science and technological cooperation under such bilateral agreements for the benefit of all parties. I wish you success in your programs and thank all of you who have assisted in putting together this symposium.

D. M. Daugherty is Senior Deputy Administrator, Office of International Cooperation and Development, USDA.

Greetings, Illinois Department of Agriculture

LARRY WERRIES

It is a privilege for me to be with you today, and on behalf of Governor James Thompson to welcome you to Illinois. I look forward to visiting your country in just a few weeks.

Accounts of your agricultural development date back thousands of years. Of particular interest to us in Illinois is the work with soybeans which began some 5,000 years ago. We are grateful to your ancestors for the start they gave us in production of one of Illinois's most important crops.

Also of great interest to me as an Illinois pork producer is your swine production. In China there is a higher productivity in numbers of pigs per litter which we in Illinois would like to adapt to our breeds. I hope to visit a hog farm during my trip to the People's Republic of China to learn more about your swine operations.

A key to agricultural progress is the exchange of information. During the history of your country, you have learned much which could prove useful to the American farmer. I think we also have learned a great deal in our country which we could impart to your benefit.

Negotiations are under way between our countries to exchange swine germplasm. We are very interested in tapping the potential of greater production per litter, and I know agricultural leaders in China are interested in the efficiency and meat production which we have bred into our animals.

An exchange of soybean germplasm would enhance ongoing research in both of our countries. It is imperative to continue working together; ultimately the results will be beneficial for both the People's Republic of China and the United States.

I hope your trip to Illinois is as beneficial as I know my visit to your part of the world will be.

L. Werries is Director of the State of Illinois Department of Agriculture, Springfield.

Greetings, University of Illinois

STANLEY O. IKENBERRY

As President of the University of Illinois, I am delighted to welcome you to the first China/USA Soybean Symposium supported by the USDA/China agricultural exchange program. We are pioneers in a new program which will continue with a 1983 symposium in China. The University of Illinois and other universities in the U.S. are actively and extensively involved in research and development for soybean use on the international level. Since these symposium and working group sessions are being supported by the U.S. Department of Agriculture, with cooperation of many universities and the private sector, it is especially pleasing to join in this work now with our friends from the People's Republic of China.

There is no subject of more fundamental importance to humankind than the provision of food and fiber. There is no task more pressing than the conduct of research and related development activities to assure that we know how to generate, produce, and control the building blocks of life itself. There is certainly no higher commitment in this regard than that of the scientific community--worldwide--to share freely in the knowledge that results from experimentation and practice.

The soybean is a plant with tremendous promise on many fronts--it is rich in nutrients; it is convertible to fuel; and it will doubtless continue to have application beyond our imagination. The soybean crop also is important to the Illinois economy. We grow some 3.645 million hectares in soybeans each year. We want to learn from and share our knowledge with all nations and people so that the fruits of knowledge can be shared widely. Since China is the home of the soybean and much experience and scientific knowledge has been accumulated, we feel scientific collaboration can be truly beneficial to American and Chinese soybean producers and consumers and to society at large.

This, then, is the part the University of Illinois is pleased to play. As you work together in the coming days, you will be doing so in the very best tradition of Illinois. May your work help us to know better not only the soybean, but also the world and each other so we can build toward a better world constructed on sound knowledge and on cooperation among nations.

S. O. Ikenberry is President of University of Illinois.

Greetings, Embassy of the People's Republic of China

WU YI-KANG

I am very pleased to have this opportunity to attend the first China/USA Soybean Symposium. First of all, please allow me to express my gratitude to the U.S. Department of Agriculture and the University of Illinois at Urbana-Champaign for their kind invitation and warm hospitality.

This is the first jointly sponsored symposium in agriculture between our two countries since the establishment of the cooperative relationship in agricultural science and technology. On behalf of Ambassador Chai Zemin and the Chinese Embassy, I would like to extend our congratulations and wish the symposium great success.

Since normalization of Sino-U.S. diplomatic relations, progress has been made in the field of scientific and technological cooperation between China and the U.S. Seventeen protocols and understandings have been signed between our two government agencies, and among them, the understanding on agricultural exchange is an important one. In the past few years, scientists of both countries have exchanged experience and learned from each other through exchange of visits, cooperative research, and bilateral symposia. As a result, their understanding and friendship have deepened and the development of science promoted. All of these are beneficial to both countries.

China and the U.S. have attached great importance to agricultural production and scientific development. China has accumulated a wealth of experience in the long process of developing agricultural production and is rich in a variety of resources, while the level of U.S. agricultural production, science, and technology is very high. Therefore, both have strong points, worth the while for each to learn, and have broad areas for cooperation in agricultural science.

Scientists from both sides will exchange results and experiences of their research on soybeans at this symposium, which will further promote the development of soybean science. It is my belief that through joint efforts the meeting will be crowned with success.

Wu Yi-kang is Counselor for Science and Technology, Embassy of the People's Republic of China, Washington, D.C.

Greetings, People's Republic of China Delegation

WANG JIN-LING

On the occasion of the China/USA Soybean Symposium held here in Urbana and on behalf of the members of the Chinese Delegation and Chinese soybean scientists, I would like to express my hearty congratulations to you all.

Both China and the U.S. are countries with vast territory and abundant agricultural resources. Since the establishment of diplomatic relations between our two countries, the exchange of agricultural science and technology and the development of scientific and technical cooperation between our two peoples have developed steadily on the basis of equality and mutual understanding.

China, where soybeans originated, is a country with a long history in soybean cultivation and therefore has made many great contributions to world soybean production. In recent decades, the U.S. has experienced rapid development in soybean production and expanded its related scientific research. The current China/USA Soybean Symposium is the first bilateral scientific symposium held between our two countries in the field of agricultural sciences. I am convinced that this symposium will be beneficial to the exchange of experiences and cooperation between the soybean scientists of both countries.

The second China/USA Soybean Symposium will be held in 1983 in China, and preparations for this second symposium have begun. We welcome American scientists to the second symposium, to be held in Jilin province in the northeastern part of our country.

We take a positive attitude towards Chinese and U.S. soybean scientific and technical cooperation. On the principle of mutual benefit, Chinese scientists are willing to cooperate in exchange of information on soybean germplasm, breeding, culture, physiology, and control of pests and disease. I am convinced that through these meetings understanding between the soybean scientists of our two countries will be further promoted and the scientific cooperation will be developed step by step and achieve better results.

Through the common effort of both China and the U.S., the China/USA Soybean Symposium is being held according to schedule. The U.S. Department of Agriculture and the University of Illinois at Urbana-Champaign have made tremendous preparations for this symposium. Upon our arrival here, we were accorded a friendly and helpful welcome from representatives of the U.S. Department of Agriculture and University of Illinois at Urbana-Champaign. On behalf of the Chinese Delegation and my Chinese colleagues present, I would like to express our hearty thanks to our American hosts and our American friends from all fields.

I wish the symposium complete success.

Wang Jin-ling is professor at the Northeast China Agricultural College, People's Republic of China.

Symposium Papers

Historical Development of the United States Soybean Industry

ROBERT W. HOWELL

The soybean industry in the United States is unique for the speed with which it grew to play a dominant role in the nation's agricultural and economic sectors. Nowhere in the country's past, nor in the history of civilization, is there another example of a crop that advanced in importance as quickly as the soybean. Soybeans now are the second most valuable crop produced in the U.S., exceeded only by maize, and are a major export commodity serving strong and stable markets in western Europe and Japan, and developing markets in Latin America and elsewhere.

Soybeans were not an important crop when Europeans were settling and developing the Americas. The historically important crops were cotton, maize, tobacco, and wheat, which provided food and fiber, and were items of commerce that formed the economic foundation of the New World. The first report of soybeans in the U.S. was 1804, when soybeans were referred to briefly in an article by J. Mease, a physician in Pennsylvania who was an enthusiastic gardener. Mease did not report the source of the soybeans in his garden but presumably they came from Asia via Europe.* By the end of the 19th century, the crop was known throughout the eastern and central parts of the U.S.

How did the soybean miracle come about? How and why was it possible for soybeans to penetrate and dominate agricultural economic systems that had been stable for centuries?

The soybean story is an illustration of the right commodity in the right place at the right time. Many factors came together to create a market and a new product which could respond to demand. Mechanized agriculture was reducing the use of animal power. The number of draft animals was declining, releasing millions of hectares that had been used to produce feed for horses and mules. Synthetic fibers were replacing cotton. Production of surplus crops was being curtailed by government policy. Meanwhile, a national shortage of vegetable oils was becoming more severe as population grew. There was growing appreciation of the importance of well-balanced protein in human and animal diets. It was known that soybeans were processed for oil and meal in China.

The situation was favorable for a new crop that would maintain farm income and contribute to the national economy. Soybeans could satisfy market demand, and proved well adapted to existing farming systems, especially in the maize system of the northern states and the cotton system of the south.

The fact that soybeans yield two products, highly unsaturated oil and protein with amino acid distribution similar to cow's milk, brought acceptance by different groups of users and provided stability as markets for oil or protein meals fluctuated.

The most important single event in soybean history in the U.S. was the appointment of W. J. Morse in 1907 as director of soybean research in the U.S. Department of Agriculture (USDA). Earlier, C. V. Piper initiated work on soybeans in the USDA. For more than 40 years, Morse promoted research, education, production, and marketing of soybeans. He was instrumental in the organization of the American Soybean Association in 1921 and served three times as its president. Morse traveled widely in the U.S., offering seed and persuading farmers to try this new crop. He spent 1929 to 1931 in China collecting soybean seeds. He led the cooperative research program of the USDA and state agricultural experiment stations, which began in 1936, until 1949.

*Author's note: Since this conference an earlier record of soybean production--by Samuel Bowen near Savannah, Georgia, in 1765--has been reported. See "The Introduction of the Soybean to North America by Samuel Bowen in 1765," by T. Hymowitz and J. R. Harlan in *Economic Botany*, volume 37 (in press).

R. W. Howell is professor emeritus and former head, Department of Agronomy, UIUC, and former leader, soybean investigations, USDA.

Soybean research began at the University of Illinois, as at many other universities, before the beginning of the 20th century. Our first research bulletin concerning soybeans was published in 1897. Soybeans have been grown at the Agronomy South Farm every year since the farm's establishment in 1903. The first breeder/geneticist with primary responsibility for soybeans at the University of Illinois was C. M. Woodworth, who joined the faculty in 1920. Woodworth was a geneticist and constructed the first chromosome map for soybeans. He developed the cultivars Illini and Chief and made the cross which led to the development of the cultivar Lincoln. Lincoln, released jointly by the University of Illinois, USDA, and several other universities in 1943, was the first cultivar to be developed from a purposeful hybridization, and the first to be produced from the cooperative program formalized in 1936.

A contemporary of Woodworth, J. C. Hackleman, was a crop extension specialist in Illinois from 1919 until he retired in 1956. Hackleman was one of the organizers of the Illinois Crop Improvement Association and an ardent supporter of soybeans. He and his extension colleagues in other states appreciated the potential of soybeans and strongly encouraged farmers to try them. Along with Hackleman and Woodworth, W. L. Burlison, head of the Department of Agronomy at the University of Illinois from 1921 to 1951, was among those instrumental in establishing Illinois as the principal soybean producing state.

Developments in Illinois were paralleled in other universities and states where interest in soybeans was growing. J. L. Cartter, a graduate student at the University of Wisconsin, was hired by USDA as a soybean agronomist in 1928 and stationed at Holgate, Ohio. In 1935, Congress enacted the Bankhead-Jones Act which provided for regional research on major agricultural problems. In 1936, under the authority of this act, the U.S. Regional Soybean Industrial Products Laboratory was established at the University of Illinois, and Cartter moved to Illinois to lead the production research at the Laboratory. In 1942, the utilization research was transferred to the Northern Regional Research Laboratory at Peoria, Illinois. The production research program remained at the University. Plant breeders were employed by USDA and stationed at Illinois, Iowa State, and Purdue (Indiana) universities, and later at Stoneville (Mississippi), North Carolina State University, and the universities of Florida, Minnesota, and Missouri.

The cooperative production research program of USDA and the states has had a strong foundation in breeding and genetics. Until recently, virtually all soybean production in the U.S. involved cultivars developed in the cooperative program of USDA and state breeders. Clark, Hawkeye, Lee, Wayne, and Williams are examples of cultivars developed in the cooperative program which have achieved dominant positions in various soybean producing areas. Some originated in Canadian programs with which U.S. researchers have cooperated closely and effectively. The group of pioneering soybean breeders, who deserve much of the credit for the success of soybeans, included R. L. Bernard, E. E. Hartwig, A. H. Probst, C. R. Weber, M. G. Weiss, and L. F. Williams. Approximately 25 states participate in the cooperative program and have designated agronomists as collaborators. However, few had active state-employed breeders prior to 1960. One state breeder who should be mentioned with the above is J. W. Lambert, University of Minnesota.

After the retirement of Morse, Weiss was leader of soybean investigations in USDA from 1949 to 1953. Then came H. W. Johnson, who, next to Morse, probably had the greatest influence on the development of soybean research. Johnson led soybean investigations from 1954 to 1964, a period during which the soybean cyst nematode was found for the first time in the U.S., the first disease-resistant cultivars were developed, and a significant increase in size and scope of soybean research staff occurred.

Prior to 1965, the only company with a soybean cultivar development program was Coker's Pedigreed Seed Co., South Carolina, where H. Webb was the soybean breeder. In 1965, a group of midwestern seed companies formed the Soybean Research Foundation, Inc., and employed A. L. Matson of Missouri as a soybean breeder. Following enactment of the Plant Variety Protection Act of 1970, which enables the developer to retain ownership and control of a cultivar as if it were patented, several companies established soybean cultivar development groups. The act stimulated interest in new techniques, such as genetic engineering, and it is probable that company-developed cultivars will occupy more of the market in the future.

B. Koehler, a contemporary of Woodworth at Illinois in the 1920's, was one of the first pathologists to become interested in soybean diseases. A few years after establishment of the cooperative program with breeders in 1936, plant pathologists were added. W. B. Allington joined the USDA group at Urbana during World War II and D. W. Chamberlain joined in 1947. Pathologists have worked closely with soybean breeders since breeding for disease resis-

tance has proved to be a powerful means of controlling soybean diseases. Soybeans so far have been spared the ravages of a major pestilence, due at least in part to vigilance of soybean workers and some brilliant research to deal with emerging problems. Phytophthora rot devastated fields in parts of Ohio and Indiana and was beginning to appear elsewhere about 30 years ago. Prompt response, notably by pathologist A. F. Schmithenner of Ohio State University, breeder R. L. Bernard (USDA), and pathologist M. J. Kaufmann at Illinois, led to discovery of genetic resistance which was incorporated by backcrossing to produce resistant cultivars of good agronomic quality. The first such cultivars were released in 1963. Additional races of *Phytophthora megasperma* f. sp. *glycinea* have appeared but the disease has been adequately controlled.

A more dramatic case involved the soybean cyst nematode. First identified in North Carolina in 1954, the cyst nematode soon was discovered in the Mississippi Delta. It is now known to be distributed in soybean production areas from the Gulf of Mexico almost to the Canadian border. Resistance to races 1 and 3 of the nematode was discovered in the cultivar Peking, which was introduced into the U.S. in 1906. Resistance involved a complex of several genes, one of which was linked closely to the gene for black seed coat, a trait unacceptable in the U.S. soybean market. However, intensive research by C. A. Brim and J. P. Ross (North Carolina), A. L. Matson and L. F. Williams (Missouri), J. M. Epps (Tennessee), E. E. Hartwig (Mississippi), and others resulted in the first commercially acceptable resistant cultivar in 1967, and others followed. However, additional races of the nematode were identified. Cultivars with resistance or tolerance are available in maturity groups for which the cyst nematode is a problem.

Research on weed and insect control in soybeans was slower to develop. In the early 1960's, there was a significant increase in weed research. During the following decade, improved weed control methods probably contributed more than any other single factor to improvement in soybean yields. Increased emphasis on insect control research is very recent, reflecting awareness of the seriousness of insect and disease losses, especially in the southern states, and the opportunities for effective and safer insect control through integrated pest management. Integrated pest management is a coordinated system of chemical, physical, and cultural pest control measures that will ensure favorable economic, sociological, and environmental consequences.

Plant physiologists have worked with soybeans for many decades. The pioneering work of H. A. Allard and W. W. Garner on photoperiodism in the second decade of this century included soybeans as one of the three crops studied. Their work and later studies on photoperiodism by H. A. Borthwick, S. B. Hendricks, and M. W. Parker led to identification of phytochrome and were the basis for the maturity group system. Soybean physiology did not become a subject of widespread interest until about 1960. Since that time, the number of physiologists and the scope of physiological research have expanded rapidly. W. L. Ogren (USDA/UIUC) and his associates have made major contributions to the understanding of photosynthesis, especially photorespiration, a process occurring in noncereals and some cereals that drains the plant of some of the product of photosynthesis. The existence of photorespiration is a major biochemical difference between soybeans and maize, effectively limiting soybean production potential to something less than that of maize.

Some proposed uses of soybeans have not succeeded. Use as a raw material for production of plastics has been mentioned frequently. About 1940, Henry Ford used plastics made from soybeans to build auto bodies. The bodies were highly resistant to damage, but other raw materials such as petro-chemicals were more economical than soybeans at the time.

Meanwhile, research expanded on uses of soybeans at the USDA laboratory in Peoria, in universities, and in industrial laboratories. At Peoria, a strong utilization research group developed under the leadership of J. C. Cowan. Others who have made significant contributions included H. J. Dutton, J. J. Rackis, A. K. Smith, and W. J. Wolf. Research on food uses at UIUC began in 1930. Similar studies were undertaken elsewhere. The great development of soybeans in the U.S. has been based on oil extraction, followed by uses of oil and oilmeal. Soybean oil is used mostly in food products, 95% of domestic use being salad oils, shortenings, and foods prepared with them. The oilmeal, high in well-balanced protein, is used in poultry and livestock feeds. Only 3% is used to manufacture industrial or human food products. In recent years, soy protein has been used to create products which simulate other foods in texture, appearance, and other qualities.

For many years there has been interest in soyfoods such as tofu, whey, cheese, and meat analogues, especially in international programs and for vegetarians. Recently, a number of soy beverage products were developed by a team including A. I. Nelson, M. P.

Steinberg, and L. S. Wei of UIUC. Interest in soyfoods seems to be increasing. A number of small companies and individuals who are interested in soybean food use have formed the Soycrafters Association, Colrain, Massachusetts. They are active in disseminating information on use of soybeans as a human food, including traditional oriental food and western dishes.

A key to the continued expansion of soybeans has been the parallel development of uses, markets, and products. In the beginning, U.S. soybeans were grown as a hay crop. The first production of soybean oil and meal in the U.S. occurred in 1911 in Seattle, Washington, with the soybeans imported from northeast China. The earliest record of processing of American-grown soybeans for oil and meal was at Elizabeth City, North Carolina, in 1915. Since 1941, soybean production primarily has been for processing and export, and hay use now is less than 1% of total production.

Farmers need assurance of a market if they are to become interested in a new crop. In the early days of commercial soybean production, this assurance was given by a few pioneering processors. In 1922, A. E. Staley, founder of the company which today has oil and meal extraction facilities in Champaign and Decatur, Illinois, and elsewhere, announced that he would begin processing soybeans that year. He guaranteed that he would buy all the soybeans that farmers would grow. Not long after, E. D. Funk, of Funk's Seeds in Bloomington, Illinois, offered a guaranteed price. Another pioneer was D. W. McMillen of Fort Wayne, Indiana, founder of Central Soya, a major processor of soybeans.

The decision of these and other business leaders to commit themselves and their organizations to soybeans, and especially their assurances to farmers, started soybeans on the tremendous expansion of the last 60 years. These steps could not have succeeded if the processors had not had markets for their products. One such early market was in New York, where the Grange League Federation needed meal for dairy cows. In subsequent years, swine and poultry feed has used a major fraction of soybean meal production. It is unlikely that the expansion of the U.S. poultry industry would have occurred without feeds based on soybeans.

From the small beginnings of soybean processing in Seattle and Elizabeth City, a strong and extensive system of soybean mills developed. The mills have become larger and somewhat fewer. There are now about 115 mills listed in *Soya Bluebook*, a publication of the American Soybean Association. A modern mill can process 2,700 metric tons of soybeans per day, requiring the production from nearly 90,000 hectares annually. Median capacity is 1,257 metric tons per day. Although soybean processing still is referred to as "crushing," the transition from extraction by hydraulic presses to solvent extraction was completed by 1970. Parallel to development of the milling industry was development of facilities for transportation, storage, and futures markets.

Establishment of the American Soybean Association in 1921 has been mentioned. The secretary of the association from 1940 until 1967 and the founder of the *Soybean Digest* in 1940 was G. M. Strayer of Hudson, Iowa. He was instrumental in guiding the soybean industry into foreign markets. In 1949 he and J. L. Cartter were the first people to be sent to Europe to explore possible markets for U.S. soybeans. After a trip to Japan in 1955, the Japanese-American Soybean Institute was formed in 1956.

The National Soybean Processors Association (NSPA) was formed in 1928 and is now a powerful organization representing the interests of the processors. The NSPA, like the growers' organization, the American Soybean Association, has been a strong supporter of research and education programs. The two associations have cooperated in market development activities abroad. Since 1948 the NSPA has sponsored the National Soybean Crop Improvement Council (NSCIC), which has an advisory board of university and USDA research administrators to promote communication between the soybean industry and soybean researchers. J. W. Calland was the first managing director of NSCIC; R. W. Judd has been managing director since 1961. Calland and Judd have contributed immeasurably to growth of the soybean industry by promoting interchange of information and by effective presentation of research needs to legislative bodies.

Support and management of soybean activities is broadly based. Farmers control much of the planning and financing of research and market promotion through a system of "check-offs," that is, a levy collected on soybeans at the first point of sale. Funds thus obtained amount to many millions of dollars, approximately US$1.5 million annually in Illinois alone. Boards or committees of farmers at the state and national levels determine how these funds will be used. There are check-off programs in 21 states, collecting 0.5 to 1 cent per bushel.

Check-off funds are allocated to market development or research and education, with somewhat more than half usually going to

market development. In addition, the Foreign Agricultural Service of the USDA provides funds through contracts for specific projects related to foreign markets. Another important component of funding comes from so-called "third parties," that is, governments or other interests in host countries.

Funds allocated for research and education supplement budgets appropriated by Congress and state legislatures, or support obtained through grants or contracts for specific projects. INTSOY, for instance, is financed almost entirely by grants and contracts. Our domestic soybean research and education program is financed by funds from all of these sources.

Soybeans have been an important part of the U.S. efforts to improve nutrition at home and abroad and to assist developing countries to strengthen their economies. Meat extenders in school lunch programs improve the nutritional status of children. Simple ("village") methods of preparing foods from soybeans were developed at Peoria and UIUC.

U.S. soybean researchers have been involved, since the end of World War II, in international assistance programs. The spectacular growth of the soybean industry in Brazil was possible in part because of training provided to Brazilians in the U.S., and more directly because of the assistance provided by U.S. scientists on long- and short-term assignments in Brazil.

UIUC has had international programs for many years. In the mid-1960's, soybeans were chosen by the University as the means of demonstrating the land-grant concept of resident instruction, research, and extension in university development contracts in India. The International Soybean Program (INTSOY) evolved directly from the soybean work in India. INTSOY programs include production and utilization research and extension teaching, with emphasis on rural or village uses that involve a minimum of processing. INTSOY successfully has completed projects in Peru and Sri Lanka and UIUC is currently beginning a new one in Zambia with a soybean development component. INTSOY, from its inception, has been a joint effort of UIUC and the University of Puerto Rico, Mayaguez Campus.

Soybean history in the U.S. is a story of many people in industry, on the farm, in government and the universities who recognized a need and opportunity. For most of this century they worked together to bring about the soybean miracle. Our industry is based on an ancient gift from the Orient. We look forward to increasing association with our colleagues from China as the soybean story continues.

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Historical Development of Soybean Production in China

MA RHU-HWA AND ZHANG KAN

Soybeans originated in China and were domesticated there. Cultivated for more than 5,000 years, soybeans are one of the ancient crops in China. According to ancient Chinese literature, soybeans were first called *shu* 𣪊, *ren shu*, or *rong shu*. The word *shu* appeared repeatedly in the *Book of Songs (Shijing)*, which is one of the Five Chinese Classics. This work spans a period of about 400 years, from the 11th century B.C. to 771 B.C., the end of the Western Zhou Dynasty. The 305 songs in the Book were divided into four time periods. The characters *shu* and *huo* 𦰩, which mean soybean leaf, appeared ten times in seven songs covering all four time periods. The name *dadou* first appeared in the *Book of Shennong* (3rd-5th century B.C.), in which soybeans were described as a crop flowering in 90 days and maturing in another 60 days. Among the inscriptions on the oracle bones of the Shang Dynasty (16th century B.C. to 1066 B.C.) was found 𦎫, which was identified later as the original form of the word *shu*.

Before 1949, the average annual soybean production in China was approximately 7 to 9 million metric tons. In 1938, it reached a record high of 11 million metric tons. By 1949, the total yield dropped to 4.6 million metric tons, and in 1952, increased to 8.6 million metric tons. In 1957, it reached 9.1 million metric tons, and by 1981 the total area under soybeans was approximately 8 million hectares with a yield of 8.4 million metric tons.

Soybeans can be grown all over China. However, they are cultivated mainly in eight provinces: Heilongjiang, Jilin, Liaoning, Hebei, Henan, Shandong, Jiangsu, and Anhui. In 1981, the area under soybeans in these provinces accounted for 76.5% of the total area under soybeans and 80.4% of the total production in China.

SOYBEAN PRODUCTION IN CHINA

Soybean production in China generally is in three regions, based on annual rainfall, mean temperature during the growth period, duration of frost-free days, photoperiodic response, and crop rotation systems.

Spring-Sown Soybean Region in the North

This region includes the northeastern provinces of Inner Mongolia, Ningxia, and Xinjiang, and the northern parts of Hebei, Shanxi, Shaanxi, and Gansu provinces. Spring-sown soybeans in the three northeastern prov inces are concentrated mainly on the Songhua jiang and Liaohe Plains, which form one of the major soybean production areas in China.

This region has one crop a year, i.e., a full-season crop. Soybeans are sown from the latter part of April to the middle of May, and harvested in September. The growth period varies from 105 to 155 days. The cultivars used in this region are not day-length sensitive, but respond to temperature and have an indeterminate growth habit. Cultivars for commercial seed production are of good quality with high oil content, yellow seed coat, light hilum, and good seed luster. Typical cultivars are Heihe No. 3, Heinong No. 26, Jilin No. 3, and Tiefeng No. 18. There are some green- and black-seeded types. The main rotation system is maize-soybeans-small grain, or soybeans-spring wheat-maize. On some state farms, a rotation system of spring wheat-spring wheat-soybeans is practiced.

Summer-Sown Multiple Cropping Soybean Region Along the Huang He and Huai He Basins

This area includes Shandong, Henan, and the northern parts of Jiangsu and Anhui, and is another major soybean production area in China. This region is the major winter wheat production area of the North China Plain, where soybeans usually are planted after winter wheat. Generally, soybeans are sown from the middle of September to the beginning of October. The growing period coincides with the rainy season when the comparatively high temperatures are favorable for

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the growth of the summer-sown soybeans. The cultivars used generally are determinate, with a yellow seed coat and dark hilum. Some green-seeded types also can be found. The growing period ranges from 95 to 110 days. Typical cultivars include Qihuang No. 1, Wenfeng No. 5, Fengshouhuang, and Xudou No. 1. Since the frost-free period can last as long as 200 to 240 days, a rotation system of two crops a year usually is practiced with winter wheat, soybeans, maize or sweet potatoes. A system of three crops in two years is sometimes practiced, e.g., winter wheat/summer soybeans/winter on fallow/ spring small grain.

Multiple-Cropping Soybean Region in the South

This region is located in the southern parts of the Huai River and the Qinling mountain range where there is abundant rainfall and high temperatures. Rice is the main crop with maize and sweet potatoes as dry-land crops, and cotton, hemp, and rapeseed as cash crops. Because of the long period of frost-free days, usually more than 240 days, cropping systems vary among two or three crops in one year, three crops in two years, or five crops in three years.

Soybeans can be sown in spring, summer, or autumn. Generally, they are rotated with rice or winter wheat, or interplanted with maize or sweet potatoes. Spring soybeans are planted in March after, or intercropped with, winter wheat or barley, harvested in July or August, and followed by rice. Summer soybeans are planted in monoculture or intercropped with maize in June after winter wheat, barley, or rapeseed, harvested in October, and followed by wheat or barley. Autumn soybeans are planted in late July after an early crop of rice, harvested in October or November, and followed by winter wheat or barley. Soybeans sown in the spring and summer enjoy optimum growing conditions with ample light and favorable temperature and moisture. Soybeans sown in the autumn, because of the shorter day length, are short and consequently have low yields. In the southern part of this region (Guangdong and Guangxi, which is frost-free all year), soybeans can be sown in winter. The main production area of this region is the Chang Jiang Valley which includes the southern parts of Jiangsu Province and northern parts of Zhejiang Province, both banks of the Chang Jiang in Jiangxi, Hubei, and Hunan provinces, the southern parts of Henan and Shaanxi provinces, and part of Sichuan province. The cultivars generally are of the determinate type with a yellow seed coat and black hilum. In some places, green-, brown-, and black-seeded types can be found. Typical cultivars of summer-sown soybeans ininclude Nannong 1138-2 and Edou No. 2. Typical cultivars of spring-sown soybeans include Tiaxing Black and Aijiaozao (Dwarf Early).

SOYBEAN RESEARCH IN CHINA

Since the founding of the People's Republic of China, soybean research work has been conducted by public institutions. The national Ministry of Agriculture includes a Bureau of Science and Technology and a Bureau of Education. The levels of research under the Bureau of Science and Technology are: national Chinese Academy of Agricultural Sciences, provincial agricultural academies and institutes, and district agricultural institutes. Under the district institutes, there are county agricultural institutes, county extension services, and county seed multiplication farms. The Bureau of Education coordinates two levels of agricultural colleges and universities: regional and provincial agricultural colleges.

In Heilongjiang and Jilin, soybean research institutes have been set up under the administration of their respective provincial academies of agricultural sciences. Soybean research laboratories were established in the Crop Breeding Institute and the Oil Crop Institute under the Chinese Academy of Agricultural Sciences, and also in Nanjing Agricultural College, which is under the administration of the Bureau of Education. There are soybean research sections in Shangdong, Henan, Anhui, and Jiangsu provinces, and also in the district agricultural institutes at the prefecture level in major soybean production areas such as Heilongjiang, Jilin, and Liaoning. Professional personnel perform soybean research work in all the provinces other than the major soybean production areas.

Soybean breeding work in China primarily uses conventional techniques. Soybeans are a self-pollinated crop, so inbred pure lines are used in breeding. We cross cultivars with desirable traits to produce lines with high yields, wide adaptability, high oil and protein content, resistance to diseases, pests, and lodging, and adaptation to mechanized harvest. Since the establishment of the People's Republic of China in 1949, we have developed more than 200 new soybean cultivars which are used in production.

We have adopted some special techniques, such as the use of mutagenic materials, in our soybean breeding research program and have some preliminary results. Research on soybean genetics, performed in the laboratories of agricultural colleges, includes heterosis and inbreeding depression,

the quantitative inheritance of economic characters, and the theory and methods of selection.

Research work on soybean germplasm has been carried out throughout the country. In general, research work on soybean germplasm has focused on three aspects: first, to describe the cultivated cultivars in terms of a series of morphological and physiological characters, including photoperiodic response; secondly, to identify the relationship between agronomic characters and ecological factors, including geography, meteorology, soil, and cropping systems; and thirdly, to identify the relationship between seed yield and other quantitative characters. Cultivated, wild, and semi-wild species of soybeans have been collected both at home and abroad. The wild and semi-wild soybean material has been sorted and identified.

Furthermore, research has been done on soybean physiology, ecology, and cultivation techniques, e.g. the study of ideotype, the physiology of high photosynthetic rate, nutrient requirements of soybeans, soil management, and irrigation techniques. In the soybean producing area of the northeastern provinces, an integrated soil cultivation system of mechanized deep plowing, loosening, and harrowing has been established.

A preliminary survey of the major diseases and pests of soybeans in China has been carried out, and research work on the pattern of outbreaks of diseases and pests, as well as their control methods, has been tackled. Research also has been done on the control of weeds by applying chemicals when cultivating. As a result of the continuous breeding work, the use of new cultivars, and the utilization of various cultural practices in soybean production, the per unit yield has been increased from 800 kg/ha in 1949 to 1,160 kg/ha in 1981, an increase of 45%.

The soybean processing industry has expanded rapidly since the founding of the People's Republic. In 1949, pressing was the only method used to extract oil from soybeans. Now, the continuous solvent extraction system is used. We use soybean meal as the raw material to produce many kinds of soybean products such as full fat soy flour, defatted soy flour, textured soy protein products, and isolated protein. These products are used in bread and many types of ininfant food.

To further develop soybean production, we shall continue to intensify our scientific research work, coordinate research, and establish soybean research centers in many soybean producing areas. We will organize a soybean research network for the northeastern region, the Huang He and Huai He basins, and the Chang Jiang Valley. We will study cultural techniques and rotation systems. We will collect soybean germplasm extensively and systematically, and identify, study, and utilize these genetic resources. We will speed up the selection, breeding, and multiplication of seeds and the employment of the new certified soybean cultivars. We will study the pattern of outbreaks of soybean diseases, pests, and weeds, and their control methods, and establish a nationwide disease and pest forecasting network. It is necessary to enhance our extension activities. Attention also will be given to the development of a modern processing industry, including the setting up of modernized processing factories and the production of various kinds of soybean foodstuffs to meet the demands of our people.

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Soybean Germplasm, Breeding, and Genetic Activities in the United States

RICHARD L. BERNARD

As a commercially significant crop in this country, soybeans have a short history and have been important in the north-central states only since 1922. They were grown earlier in the southeast, especially North Carolina, as a forage crop. Breeding in those early years consisted of field trials of cultivars introduced from Asia and choosing those best adapted and most productive for the local farmers.

Soybeans were experimented with in small plantings and occasionally grown on a commercial scale during the 1800's. According to Piper and Morse (1923) no more than eight cultivars were grown in the U.S. prior to 1898. In that year the U.S. Department of Agriculture (USDA) began a program of recording introduced cultivars of crop plants under "PI" designations. Through this system, large numbers of soybeans were introduced and grown in experimental plots. The better ones were sent out to various state experiment stations for further testing.

From 1898 to 1923 more than 1,000 cultivars were introduced, most sent by research stations or grain merchants in Asia, or brought in by agricultural explorers, diplomats, missionaries, or other travelers to Asia (Table 1). Some of the most successful cultivars were introduced into the U.S. during this period. As a result of the increasing success of soybeans, the USDA sent plant explorers to Asia (notably P. H. Dorsett and later W. J. Morse) and from 1924 to 1932, 6,651 soybean accessions were introduced. During the next 40 years little effort was made and only a few soybeans were introduced each year. With renewed interest since 1975, more than 5,000 strains have been introduced.

During the early periods of introduction no attempt was made to save all the strains introduced and a majority of them were discarded. Only the best were kept along with some of the unusual types. In 1949, in recognition of the need to preserve the germplasm of this important crop and make it readily available, the USDA established a soybean germplasm collection. The early strains (Group IV and earlier) are maintained at the University of Illinois at Urbana-Champaign and the later ones (Group V and later) at the Delta Branch Experiment Station, Stoneville, Mississippi. The collection was initiated by M. G. Weiss, head of USDA's soybean production research, and

Table 1. A statistical history of soybean introductions

Period	Years	Number of soybean PI numbers	Rate/yr	Number in germplasm collection
1898-1923	26	1,053	40	132
1924-1928	5	1,878	375	303
1929-1932	4	4,773	1,193	1,051
1933-1944	12	169	14	35
1945-1974	30	2,556	85	2,095
1975-1980	6	5,001	834	5.635
Total or average	83	15,430	186	9,251

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J. L. Cartter, head of the U.S. Regional Soybean Laboratory at Urbana. The original curators were E. E. Hartwig at Stoneville and L. F. Williams at Urbana. Hartwig is still curator of the southern collection. R. D. Osler succeeded Williams in 1951, and I became curator of the northern collection in 1954.

The guiding principle has been to maintain the basic genetic diversity of the soybean and its wild relatives by maintaining all cultivars and introductions representing different germplasm, regardless of their apparent economic worth, and to make them readily available for research purposes.

In 1949 and 1950, the USDA and state agricultural experiment stations were requested to submit samples of all introduced strains and old U.S. cultivars. From the 7,873 PI strains introduced before 1945, 1,659 strains were obtained, including 138 old U.S. cultivars that originated from introductions (Table 1).

Introduced strains plus American-developed cultivars have been added to the collection since then, until today the number of soybean entries totals over 9,500, about 70% are in the northern collection and 30% in the southern one. They were drawn from 60 countries, but the majority came from eastern Asia and especially from China (1,202 strains), Japan (1,721), Korea (3,041), and the Soviet Union (1,847) (Table 2). Soybeans from these four countries comprise 83% of the collection and many of the strains received from other countries originated from these four. At Urbana, in addition, there is a genetic collection (mutations, oddities, isolines, etc.) of several hundred lines of interest in qualitative genetic studies. We maintain also a collection of wild soybeans, *Glycine soja*. The wild soybean accessions range in maturity from Group 00 to X and were obtained in the USSR (34 accessions), China (28), China (Taiwan) (2), Korea (313), and Japan (183). Because they can be crossed with cultivated soybeans, they are an interesting potential source of useful germplasm. We have also a collection of six perennial species of *Glycine*. These species are native to Australia and some range into the south Pacific islands and south China. Though not closely enough related for easy crossing with soybeans, these species are of interest in studies on the origin of soybeans and botanical relationships within the genus. If the crossing barrier can be overcome, they may supply the soybean breeder and geneticist with some interesting and diverse material.

The soybean germplasm collection is used actively by researchers throughout the U.S. and from many other countries. In 1982, from the collection at Urbana, we expect to send out over 40,000 seed lots.

We hope to obtain as much of the world's wild soybean germplasm as possible, and to complete our collections from Europe, the USSR, southern Asia, South Korea, and Japan. Our greatest need is for further collections from North Korea and China, especially southern and western China, since most Chinese strains in the present collection have come from northeastern and north-central China.

Of the 7,000 soybean cultivars introduced before 1945, more than 200 were named and promoted for commercial use in this country. References listing or describing these old cultivars appear at the end of this paper. Some of the older cultivars had small black and brown seeds with bushy or viny-type plants suited for hay production, which was a major use of soybeans in this country until the 1940's. Some of them were large-seeded vegetable types grown for direct human consumption in home gardens and occasionally on a small commercial scale. Most of them were grain-type soybeans. It was with these cultivars selected from introductions from eastern Asia that the U.S. soybean industry was built, since it was not until the 1940's that soybeans were developed from artificial hybridization for specific adaptation to this country.

Virtually all of the successful cultivars for oil-seed production in the north-central states were from northeast China, which has similar climate and where large scale commercial soybean production had already been under way for several decades. Thus the successful establishment of the U.S. soybean industry was based on the successful development of a similar industry of soybean production and oil extraction in northeast China. We owe a debt of gratitude to the unknown Chinese plant breeders or farmer-selectors who developed these basic commercial-type soybeans.

Beginning in the late 1930's and 1940's, soybean breeders in the USDA-state experiment station breeding programs, through hybridization and selection, developed improved cultivars with higher yielding ability and resistance to lodging and shattering and to prevalent diseases. By the 1950's virtually all hectarage was planted to these products of the scientific breeders' art, yet even down to the present day these American cultivars trace their ancestry to a small group of successful introductions, largely from northeast China.

Mandarin was introduced from Sui Hua in Heilongjiang Province in 1911. It or a selection named Mandarin (Ottawa) is present

Table 2. Number of strains in the USDA germplasm collection (FC, PI, Variety) by country of origin (1900 to 1980, to PI 452.071)

	Total	North	South
Asia			
Afghanistan	5	0	5
Burma	3	0	3
China	1,202	1,070	132
China (Taiwan)	26	2	24
India	230	2	228
Indonesia	28	0	28
Iran	1	1	0
Israel	13	7	6
Japan	1,721	1,073	648
Korea	3,041	1,827	1,214
Malaysia	30	0	30
New Guinea	1	0	1
Nepal	30	0	30
Pakistan	15	0	15
Philippines	18	0	18
Thailand	34	0	34
Turkey	6	5	1
Vietnam	5	0	5
Total	6,409	3,987	2,422
USSR			
USSR	1,847	1,805	42
Europe			
Austria	2	2	0
Belgium	88	88	0
Bulgaria	44	44	0
Czechoslovakia	6	6	0
England	1	1	0
France	103	103	0
Germany	88	88	0
Hungary	106	106	0
Italy	1	1	0
Netherlands	21	21	0
Poland	46	46	0
Portugal	3	3	0
Romania	156	156	0
Sweden	56	56	0
Yugoslavia	38	38	0
Total	759	759	0
Africa			
Algeria	1	1	0
Angola	7	0	7
Cameroun	2	0	2
Kenya	3	0	3
Liberia	1	0	1
Mozambique	6	0	6
Nigeria	13	0	13
Sierra Leone	1	0	1
South Africa	32	0	32
Sudan	3	0	3
Tanzania	7	0	7
Uganda	31	0	31
Zaire	2	0	2
Zimbabwe	6	0	6
Total	115	1	114
Australia			
Australia	31	7	24
North America			
Costa Rica	1	1	0
El Salvador	3	0	3
Guatemala	3	0	3
Mexico	1	1	0
United States	72	32	40
Total	80	34	46
South America			
Argentina	7	1	6
Brazil	16	0	16
Colombia	5	0	5
Peru	8	1	7
Surinam	14	0	14
Uruguay	5	5	0
Venezuela	10	0	10
Total	65	7	58
Misnumbered PI	37	31	6
Grand total	9,343	6,631	2,712

in the ancestry of all major northern cultivars. Manchu, introduced in 1911 from Ning'an in Heilongjiang Province, is in the parentage of most northern cultivars. From AK, introduced in 1912 from an unknown place in northeast China, two apparently identical selections named AK (Harrow) and Illini were made (in Ontario, Canada, and Illinois, respectively) and used in producing nearly every northern and southern cultivar. Dunfield from Fanjiatun, Jilin Province, in 1913, is in the ancestry of many northern and southern cultivars. Mukden, introduced from Shenyang in Liaoning Province in 1920

and Richland from Changling, Jilin Province, in 1926, are important also in the pedigrees of northern cultivars.

These six, which were widely grown in the 1930's and early 1940's and which are preserved in the germplasm collection, along with five others (one from Japan, one from Jiangsu, China, and three from northeast China including PI 54610 from Changchun, Jilin, in 1921) have produced all of the widely grown cultivars in the north (Table 3).

In the south, three of the above cultivars from northeast China, AK (through the late selection, S100), PI 54610, and Dunfield, appear in the ancestral parentage, but there also are important introductions from further south (Table 4).

Tokio, introduced from Japan in 1901, is in the pedigree of every major southern cultivar and some of the northern. Arksoy and Haberlandt from Pyongyang, Korea, in 1914 and 1901, respectively, are in a majority of southern cultivars. CNS, which is in the ancestry of all southern and several northern cultivars, Roanoke, and Palmetto all were obtained from the University of Nanjing in 1927. (Roanoke is a reselection, possibly from an outcross.)

Table 3. Ancestry of major soybean cultivars, north-central U.S., 1980

		Ancestral Asian cultivar and source										
U.S. cultivar	% of area[a]	Mandarin (NC, 1911)	AK (NC, 1912)	Manchu (NC, 1911)	Richland (NC, 1926)	Mukden (NC, 1920)	Dunfield (NC, 1913)	PI 54610 (NC, 1921)	Tokio (J, 1901)	CNS (C, 1927)	No. 171 (NC, 1931)	PI 180501 (Germany, 1949)
Williams	24.5	x	x	x	x		x			x		
Corsoy	9.3	x	x								x	
Amsoy[b]	4.4	x	x			x[c]	x					
Wells	3.3	x	x	x	x	x		x	x			
Hodgson	3.2	x	x	x	x						x	x
Wayne	3.0	x		x	x					x		
Woodworth	2.9	x	x	x	x		x			x		
Calland	2.8	x	x	x	x	x		x	x			
Beeson	2.0	x	x	x	x	x		x	x			
Evans	2.0	x	x		x	x					x	
Total	57.4											

x means that the Asian cultivar at the top of the column is in the ancestry of the U.S. cultivar listed on the left. C = China, NC = northeast China, J = Japan, K = Korea.

[a]Percent of soybean hectarage in eight north-central states (total, 16 million hectares; U.S. total: 28 million hectares).

[b]Includes cultivars Amsoy and Amsoy 71.

[c]Mukden is in the ancestry of Amsoy 71 but not of Amsoy.

Table 4. Ancestry of major soybean cultivars, south-central U.S., 1980

		Ancestral Asian cultivar and source												
U.S. cultivar	% of area[a]	CNS (C, 1927)	AK (S100) (NC, 1912)	PI 54610 (NC, 1921	Tokio (J, 1901)	Arksoy (K, 1914)	Roanoke (C, 1927)	Dunfield (NC, 1913)	Palmetto (C, 1927)	Haberlandt (K, 1901)	Peking (C, 1927)	Patoka (NC, 1926)	PI 81041 (J, 1929)	PI 88788 (NC, 1930)
Forrest	15.8	x	x	x	x			x	x	x	x			
Bedford	13.1	x	x	x	x			x	x	x	x			x
Bragg	11.0	x	x	x	x				x					
Centennial	9.9	x	x	x	x	x		x	x	x	x			
Essex	9.4	x	x	x	x		x					x	x	
Davis	9.1	x		x	x	x	x							
Lee[b]	7.6	x	x			x[c]								
Ransom	4.5	x	x	x	x	x	x		x	x		x	x	
Total	80.1													

x means that the Asian cultivar at the top of the column is in the ancestry of the U.S. cultivar listed on the left. C = China, NC = northeast China, J = Japan, K = Korea.

[a]Percent of soybean hectarage in six south-central states (total = 8 million hectares)

[b]Includes cultivars Lee, Lee 68, and Lee 74.

[c]Arksoy is in the ancestry of Lee 68 and Lee 74. Lee 74 also has FC 33243, of unknown origin, received in 1949.

Two dark-seeded types, Peking from Beijing in 1906 and PI 88788 from Liaoning Province in 1930, have been used for their cyst nematode resistance.

These 11 plus three others (one from northeast China, one selected from a strain from Japan, and one of unkown origin) comprise the ancestry of all the major cultivars in the south. Most of the lesser grown cultivars, north and south, have the same ancestry. Thus fewer than 20 introductions have given rise to the cultivars now grown throughout the U.S., although many other introduced cultivars have been used in the various breeding programs across the U.S. and Canada.

The breeding programs that led to today's commercial cultivars are a joint USDA-state experiment station effort that began in 1936 with the establishment of the U.S. Regional Soybean Laboratory (USRSL) at Urbana, Illinois. Under the directorship of J. L. Cartter and later R. L. Cooper, the USRSL coordinated a regional testing program of federal, state, and Canadian soybean breeders, pathologists, entomologists, and physiologists working to develop commercial soybean cultivars. The public soybean breeding program has grown from a small group of less than 12 full-time soybean breeders in the 1950's to 72 in the latest listing of public soybean breeders and geneticists in the U.S. and Canada. To this group has been added, mostly during the past ten years, some 60 professional breeders working for approximately 26 private seed companies. All are actively engaged in developing improved cultivars for the American farmer.

The cooperative regional testing program among public breeders has been an important factor in the development of well-adapted cultivars. There is a regional test for each maturity group, and each breeder enters his best experimental lines. By testing in a large number of locations widely scattered from east to west over the latitude where the maturity group is adapted, cultivars are selected that are well suited to the changeable weather conditions that occur from year to year. From this testing program have come all public cultivars now grown on over 80% of the U.S. hectarage. The testing is coordinated in the south by E. E. Hartwig, Stoneville, Mississippi, and in the north by J. R. Wilcox, Purdue University, West Lafayette, Indiana, and involves some 50 researchers in 29 states and two provinces in Canada.

Breeding objectives vary somewhat from region to region. Direct selection for improved yield, aside from any pest resistance or morphological differences, has been perhaps the most important advancement of present-day cultivars over the introduced cultivars. Other traits that have been markedly improved are lodging resistance, which allows soybeans to be grown in higher populations and close together in widely spaced rows to facilitate tractor cultivation; shattering resistance, which allows the ripe soybeans to stand in the field without loss until the weather is right for mechanized harvest and also reduces combine losses; and improved seed quality, which facilitates the production of good, sound, and germinable seed even under conditions of adverse heat, drouth, and disease. Some improvement in oil content has been achieved, but because oil and protein content are strongly and negatively correlated, there is less effort in recent years to increase oil. Potential cultivars are tested to be sure there is no decrease in the combined value of oil and protein.

Major improvements have been made in pest and disease resistance, especially in recent years. The ancestral cultivars chosen in this country had moderate levels of resistance to such common diseases as bacterial blight (*Pseudomonas syringae* pv *glycinea* (Coerper) Young) and soybean mosaic virus. Many introduced cultivars are susceptible to potato leafhopper (*Empoasca fabae* (Harr.)) damage because they do not have erect pubescence. Thus, erect pubescence was indirectly favored in the initial selection of cultivars and is present in all U.S. cultivars today.

One of the earliest breeding programs for disease resistance used a gene for resistance to bacterial pustule (*Xanthomonas campestris* pv *phaseoli* Smith (Dye)) found in the cultivar CNS. Most introductions are susceptible to this common disease, but today all southern cultivars and many grown in the southern part of the north-central states contain this CNS resistance. Phytophthora root rot (*Phytophthora megasperma* (Drechs) sp. *glycinea)* has caused major soybean losses in the past but today is controlled in part by resistant cultivars. Many races of the pathogen were discovered in recent years but resistance has been found to each, and breeding programs are under way to combine as many genes for resistance as possible into each new cultivar to combat this multitude of races. Brown stem rot (*Phialophora gregata* (Allington and Chamber.) Gams) is one of the more common diseases of soybeans, especially when soybeans follow

soybeans in the rotation. Several cultivars specifically bred for resistance have recently been released in the north. In the south nematodes have been a problem, and cultivars bred for root-knot nematode (*Meloidogyne* spp.) resistance have been important in some areas. More recently soybean cyst nematode (*Heterodera glycines* Ichinohe) has has become a widespread problem, and several resistant cultivars have been released and are rapidly occupying a major part of the soybean hectarage in the south.

In the future, soybean pests and diseases will likely be an even more important factor in soybean production. Soybean breeders will be putting more emphasis on increased cultivar resistance and will be selecting for multiple resistance to different races and types of diseases.

Breeders constantly are looking for the traits that contribute to improved yield. Because of the low heritability of yield, selecting for component traits rather than directly for yield might improve breeding efficiency. Unfortunately, except for pest and disease resistance, no helpful physiological or morphological traits have been found. The length of the pod-filling period is being studied by some researchers since it has been noted that our adapted high-yielding cultivars have longer periods of flowering-to-ripening than most soybeans. Studies of photosynthetic rate difference and other physiological processes have not yet demonstrated useful ways of improving yield. Pubescence-type differences are important because of their effect on insect resistance. Narrow leaflet types are grown to some extent, but this leaf type does not appear to affect yield. Improved lodging resistance is an important goal which has been achieved through both shorter plants and stronger stems.

Stem type is a major factor affecting the growth of the soybean plant. In the northern U.S. almost all cultivars (Group IV and earlier) have indeterminate stem growth and all southern ones (Group V and later) have determinate stem growth. This is probably in part an adaptation to the climate of the regions; indeterminate types tend to promote needed stem growth in the cooler, shorter season of the north and the determinate type restricts excessive growth in the warmer and longer season of the south. Nevertheless there has been some success with an indeterminate cultivar in the south for late planting after wheat harvest, and several short determinate cultivars have been recently released in the north. These have had excellent yields under some conditions but tend to have problems when growing conditions are adverse. An intermediate type called "semi-determinate" also is being considered, and one such cultivar was released in Illinois and nearby states in 1979.

Improvement in yield through improved soybean cultivars has been slow but steady over the past 40 years. No slowdown has yet occurred and presumably further improvement is possible working with the rather narrow base of just 20 ancestral cultivars. A major problem for the breeder is how to effectively use the large number of germplasm lines and find sources for further improvement. A preliminary evaluation and description of each germplasm entry is made at Urbana and Stoneville. Cooperative efforts among public and private breeders to further evaluate the yield potential of introductions is under way. It seems likely that, at least in the near future, U.S. cultivars will continue to be based mostly on the same germplasm as in the past with gradual additions of a few specific traits such as pest resistance, improved seed composition, or better plant growth traits selected from the large germplasm collection. Advances in the future will be more difficult than in the past, but with the large number of specialists working on the problem the prospects are bright for considerable further improvement in soybean production through improved cultivars.

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Ecological Distribution of Soybean Cultivars in China

WANG JIN-LING

Studying the germplasm of crop plants from an ecological point of view can help us understand the geographical distribution, development, and function of crop characteristics. We should deliberately collect, study, and utilize this germplasm.

The inheritance of most agronomic characteristics of soybeans is quantitative, and their genetic variance is additive. The large and continuous genetic variation of such characteristics allows selection by various environmental conditions, and thus produces many types and cultivars. In China, except in Qinghai and Xizang provinces and certain other cool, high mountainous regions, soybeans are grown wherever there is crop production. The adaptability of soybeans is chiefly due to their wide variability. Each climatic pattern, crop rotation system, and use of soybeans has its own adaptable cultivars. This has produced the large pool of Chinese soybean germplasm.

ECOLOGICAL GEOGRAPHY OF GROWTH PERIOD OF SOYBEANS IN CHINA

The growth period of soybeans has been classified into 13 maturity groups (000 to X). The geographical distribution of these maturity groups is related to latitude. However, the diversity of crop rotation systems in different regions complicates the distribution of soybean maturity groups.

In the northeast and northern parts of China, there is only one crop each year (Fig. 1). Soybean cultivars in the extreme northern part of this region belong to maturity Group 00, those in the middle to Group II, and those in the south to Group III.

In the plain between the Huang He (Yellow River) and the Huai He, there are two crops each year. The main crop rotation system is winter wheat-summer soybeans or sweet potatoes. Soybeans in this region are planted after winter wheat harvest, as late as the middle of June. Since their growth period is only 110 days, they are classified into maturity groups V and VI. In this region, some spring-sown cultivars belonging to maturity groups III and IV also are planted.

In the broad Chang Jiang (Yangtze River) Valley, the frost-free season lasts 250-300 days, and there is considerable variation in day length and topography. Under such conditions cropping systems which include soybeans are complex. Most soybeans sown in the spring belong to maturity groups I and III, most soybeans sown after winter crops belong to groups VI and VII, and most autumn soybeans sown after early rice belong to groups VIII and IX. The actual growing period of summer and autumn soybeans is only 95-100 days. The cultivar Biloxi, used for the study of photoperiodism, is one such autumn soybean. There are more soybean cultivars in the Chang Jiang Valley than in other regions.

In the extreme southern portion of China, there is a frost-free belt where the mean winter temperature is as high as 18-20° C, and day length throughout the year is comparatively short. In this region, soybeans belonging to groups V and VI can be grown all year round, while those of groups VII and VIII are sown in May, and those of groups IX and X in late July.

Differences in growth period are a reflection of varietal response to photoperiod. Wang et al. (1956) sampled 24 common cultivars from different latitudes in China and tested their photoperiodic response to different day lengths (Table 1). Soybeans in the extreme northern part of Heilongjiang Province (50° N) are day neutral, while those of Guangdong Province (22.5° N) are short-day plants. Between these two extremes are the consecutive transitional forms. Soybeans from the Chang Jiang Valley (30-32° N) consist of nearly day neutral, moderate short-day, and typical short-day types.

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Figure 1. Soybean production regions in China.

Wang (1980) tentatively has classified the growth period of soybeans from China into 12 maturity groups. He sowed the entire collection in early April at Wuhan (30° N) to let the plants grow under lengthening day conditions (Table 2). His classification is roughly in accordance with the classification already widely used.

Under long days and cool conditions of the high latitudes, day-neutral or weakly short-day types could be adapted. Very early types (000 Group) can be developed through hybridization for expansion of soybean production to higher latitudes or cooler areas. Under short-day conditions, only typical short-day types can produce vegetative growth and high yields (Table 3). The typical short-day types (groups IX and X) are valuable sources of germplasm for tropical soybean breeding programs. Using Chinese soybean germplasm of different maturity groups, any kind of maturation type can be obtained through pure line selection or hybridization.

ECOLOGICAL DISTRIBUTION OF SEED SIZE

We believe that large-seeded *Glycine max* were derived from small-seeded *G. soja* through long-term selection under intensive cultivation. Larger-seeded soybeans are more adaptable to intensive farming than the small-seeded types. The ecological reaction of soybean types of different seed size can be observed from the geographic distribution of seed size of Chinese soybeans.

Generally, soybeans produced in the northeast have 100-seed weights ranging from 18 to 22 g. In the western part of the northeast, where annual rainfall is only 400-500 mm and soil is more or less alkaline, 100-seed weights range from 13 to 16 g.

In the loess plateau area of the Shaanxi and Shanxi provinces, where the annual

Table 1. Photoperiodic response of soybean cultivars sampled from different latitudes in China (Wang et al. 1956)

Origin of cultivar	Latitude (degree N)	Day length on summer solstice (hr)	Cultivar	Days from seeding to blooming under different day lengths: 13.5 hr	14.5 hr	Natural day length	17-18 hr	Continuous light
Aihui	50.0	16:30	Keisum	49	49	50	51	51
Harbin	46.6	16:00	Mantsunchin	50	50	55	72	99
Beijing	40.0	15:10	Tonshando	61	65	91	117	no bloom
Dangshan	34.5	14:35	Big Cocoon	65	78	96	119	no bloom
Nanjing	32.0	14:20	Spring Early	52	53	53	65	79
Nanjing	32.0	14:20	N. K. 332	68	115	no bloom	no bloom	no bloom
Hangzhou	30.0	14:10	September	74	no bloom	no bloom	no bloom	no bloom
Guangdong	22.5	13:35	Dootzu	76	no bloom	no bloom	no bloom	no bloom

Table 2. Classification of growth period of Chinese soybeans (Wang, 1980)

Group	Days to maturity	Typical cultivar
I	Within 80	Kusan
II	80-90	Xiaochinhuang
III	91-100	Fushau
IV	101-110	Shuchow Bean
V	111-120	Chihuangdo
VI	121-130	Monkey Hair
VII	131-140	Yiulin Yellow
VIII	141-150	Nannon 493-1
IX	151-160	Cross Road 1
X	161-170	Yiulin Red Hair
XI	171-180	Beinido
XII	Over 181	Nanwando

rainfall is 400-500 mm and soil fertility is low, small (13 g per 100 seeds) black-seeded soybeans are the dominant type.

In the plain between the Huang He and Huai He Valley, where soybeans are planted after winter wheat and used for local consumption, the seed size ranges from 13 to 16 g per 100 seeds.

In the Chang Jiang Valley, soybean seed size varies according to usage and cropping systems. The seed size of some vegetable-type soybeans may be 38-40 g per 100 seeds while those used for vegetable sprouts may be 4.5 g per 100 seeds. Most autumn soybeans sown in late July after rice are small-seeded. Seeds from soybeans sown after winter crops range from 10 to 15 g per 100 seeds.

The inheritance of seed size of soybeans is quantitative, so the potential for selection among progenies of crosses is great. When the breeding objective is larger seed, parental material with different ecological and geographical origins should be used for crossing, and transgressive inheritance of seed size may be used for larger seed selection.

ECOLOGICAL DISTRIBUTION OF POD-BEARING CHARACTERISTICS

Soybeans of indeterminate type (Dt_1dt_2) perform better than determinate type (dt_1) under water stress, low fertility, and short

Table 3. Yield performance of different maturity types of soybeans at Zhanjiang, Guangdong Province, 1981

Cultivar	Latitude of origin (N°)	Maturity group	Growth period at Zhanjiang (days)	Yield per plot (g)
Heihu 3	50°15'	00	77	14.7
N. E. 4	45°41'	I	82	67.2
Dando 2	40°28'	II	81	265.0
Yuido 2	30°38'	VII	78	261.1
Chudo 1	26°55'	IX	96	483.8
White Flower 1	21°15'	IX	68	320.8

growing season conditions because of more prolific growth. Determinate soybeans produce greater yields under more intensive cultivation because of their resistance to lodging and less excessive vegetative growth. Semi-determinate soybeans (Dt_2) are intermediate between the two types. Therefore the geographical distribution of pod-bearing characteristics of soybeans corresponds closely with ecological surroundings. The general ecological distribution of soybean pod-bearing characteristics in China is shown in Table 4.

Determinate soybeans are prevalent in the Chang Jiang Valley. Soybeans in the the southeast part of Liaoning Province also are mostly determinate. Germplasm from these areas is valuable for breeding for lodging resistance.

Indeterminate and semi-determinate soybeans from the main soybean producing area of the northeast are promising for developing cultivars with tall, stiff, developed main stems with moderate branching, more nodes on the main stem, and suitable for mechanized harvesting.

Indeterminate soybean germplasm, tolerant to stress conditions such as low rainfall and low soil fertility, can be obtained from Inner Mongolia, the Huang He Valley, and northern Shaanxi and Shanxi provinces.

CHEMICAL QUALITY

There is an ecological distribution of soybean protein and oil content in China (Table 5). In places where daytime temperatures range between 30 and 32°C and nighttime temperatures 19-20°C, with adequate rainfall and sunlight, soybeans have high oil content but moderate protein content.

Soybeans are low in oil but high in protein content in arid or very humid areas, in hot areas where difference between day and night temperatures is small, or in areas

Table 4. Ecological distribution of pod-bearing characters of Chinese soybeans

Area	Indeterminate (%)	Semi-determinate (%)	Determinate (%)
Harbin district	87.0	--	13.0
Central Jilin province	57.2	26.2	16.6
South East Liaoning	22.0	--	78.0
Xuzhou, Jiangsu province	34.0	--	66.0
North and Central Shanxi	94.0	--	6.0
Inner Mongolia	95.0	--	5.0
Chang Jiang Valley	15.0	--	85.0

Table 5. Oil content of soybeans from different localities of China and their variation under different date of seeding at Wuhan (Wang, 1979)

District of origin of seeds	Cultivar	Original % of oil	% of oil by seeding	
			March 4	July 27
Northeast	Kusun	21.5	25.9	21.1
	Purple Flower 4	20.5	23.4	15.4
	Fushau	20.8	24.1	17.5
Huang He Valley	New Yellow	20.4	22.9	18.0
	Tawny Hair	19.7	20.9	18.5
Chang Jiang Valley (summer soybean)	Cross Road 1	18.7	20.9	16.1
	Monkey Hair	19.4	16.6	16.9
Chang Jiang Valley (autumn soybean)	Beinido	18.8	18.1	15.8
	Black Pod	16.5	17.5	16.2
	Heinido	13.1	13.5	11.0

where the mean temperature during the blooming and pod-bearing period is lower than 20°C.

Soybean germplasm from the Chang Jiang Valley is valuable for its high protein content (45%), especially the summer and autumn soybeans. Protein content of Biloxi soybeans is as high as 48%. Fei and colleagues (1981) analyzed protein and oil content of 1,217 soybean accessions collected from Jiangsu Province. The range of oil content of these materials was 11.6-22.4%, and the average was 17.9 $\pm$ 1.4%. The range of protein content was 37.5-48.5%, and the average was 43.9 $\pm$ 1.2%. Protein content of 51.4% of the accessions was over 44.0%.

Soybean cultivars collected from the main soybean producing area of the northeast have a high oil content (20-23%) and a moderate protein content (37-40%). Cultivars with an oil content of 22-24% can be found frequently in the northeast, but soybeans with protein content higher than 43% are rarely found.

Long-term selection for specific usage played an important role in the chemical composition of Chinese soybeans. Soybeans produced in the northeast were used chiefly for oil, in the Chang Jiang Valley for foodstuff, and in the Huang He and Huai He Valleys for both.

Ting (1957) has studied the ecological distribution of iodine content of soybean oil in China. Iodine content of soybean oil is closely correlated to latitude (r=0.969). An increase of one degree North is accompanied by the rise of 1.729 points of iodine in soybean oil (Table 6).

DISEASE AND INSECT RESISTANCE

Much of the Chinese soybean germplasm is resistant to diseases and insects. Results of studies in the U.S. indicate that Peking was the first donor of the gene for resistance to the soybean cyst nematode. Resistance to bacterial pustule came from CNS, a native cultivar of Nanjing. Mukden, a cultivar from the district near Shenyang, was the source of resistance to Phytophthora rot and several races of downy mildew. Laredo and Palmetto, originating from the Chang Jiang Valley, were sources of resistance to root-knot nematode. Many Chinese soybeans were sources of resistance to frogeye leaf spot. Preliminary studies by Chinese scientists show that several cultivars are moderately resistant to soybean mosaic virus. Through screening, 15 out of 28 soybean accessions from Hubei Province were found to be highly resistant to wildfire disease (Shu, 1980).

The mode of inheritance of resistance to most soybean diseases is qualitative. Therefore, epidemic conditions of diseases are not the prerequisite for the presence of resistant genes. Clark 63 yields almost as much as Clark under disease-free conditions. Under epidemic conditions of Phytophthora rot, yield of Clark 63 is twice that of Clark. Peking was collected from Beijing where cyst nematode is not a problem, and Mukden came from Shenyang where Phytophthora rot disease is not prevalent. Although sources of genes for resistance to soybean diseases may be present in soybean germplasm grown in many places in China, they can only be identified through screening. We should collect soybean accessions from both the epidemic and disease-free regions.

In northeast China, 2,008 accessions were screened for resistance to pod borer (*Leguminivora glycinivorella*, Lepidoptera: Tortricidae). The cultivar Iron Pod was used as a source of resistance, and several cultivars were developed and released. Larvae mortality on the resistant cultivar Kilin 3 was as high as 88%, while on the susceptible Jiunong 9 was 21.7% (Guo, 1981).

SEED COAT AND PUBESCENCE COLOR

Most small-seeded, primitive (vine type) soybeans have black or brown seed coats and perform well under stress. The loess plateau of north Shanxi and Shaanxi provinces grows small-seeded black soybeans. In places where soybean production is high and soybeans are produced commercially, seed coats are mostly yellow. Near urban areas, green seed-coat

Table 6. Iodine content of soybean oil in relation to latitude N (Ting, 1957)

	Localities and latitude N						
Cultivar	Guilin (25°14')	Nanchang (28°41')	Hangzhou (30°16')	Wuchang (30°32')	Nanjing (32°03')	Xuzhou (34°14')	Beijing (40°00')
Shiyebei	104.4	106.1	108.2	108.7	110.3	113.3	122.8
Luiyebei	104.5	119.1	110.0	119.4	114.8	120.2	141.7

Table 7: Geographical distribution of soybean seed coat color in China

Localities	Percentage of accessions of different seed coat color			
	Yellow	Green	Black	Brown and bicolored
Central and north part of Northeast	93	2	2	3
North Shanxi and Shaanxi provinces	10	--	85	5
Plain between the Huang He and Huai He	78	9	8	5
Chang Jiang Valley	83	8	3	6
South Hunan and Zhejiang provinces	40	27	20	13

soybeans usually are grown as a vegetable. In China, a regular pattern of geographical distribution of seed color is evident (Table 7).

The gene T causing tawny pubescence on soybeans also may cause black hilum when it is complementary with gene R, and causes brown hilum when it is complementary with gene r, provided gene i^i is present. Soybeans with genotypes Rt and rt give gray pubescence and a buff hilum. In the northeast, traditional soybeans are grown as a commercial commodity, and soybeans with light hilum color are preferred. Most cultivars from the main producing area of the northeast have gray pubescence. In the Huang He Valley, there is an equal proportion of gray and tawny pubescence color. In some areas of the Chang Jiang Valley soybeans with tawny pubescence and dark hilum are dominant. In southern China, autumn soybeans following early rice mostly have a tawny pubescence. The small-seeded, black or brown soybeans in the loess plateau all have tawny pubescence.

The study of ecological distribution of soybean cultivars is helpful for developing breeding objectives in soybean breeding programs.

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An Overview of Cultural Practice Activities of Soybeans in the United States

WALTER O. SCOTT

Only 30 states, all located east of the Continental Divide, produce soybeans in quantities large enough to be included by the statistical service of the U.S. Department of Agriculture (USDA) in its crop production reports. Soybeans may be produced in other states such as California and Oregon, but they are not economically competitive with other crops in those states.

The production area stretches about 2,600 kilometers from north to south and about 1,500 kilometers from east to west. The length of the growing season varies from an average of 100 days in the northern part of the country to more than 300 days in the southernmost areas.

The day length in the northern section is much greater than the day length in the south. The longest day of the year is three hours longer from sunup to sundown in the north than in the south. This difference in day length is responsible for a wide variation in cultivars grown in the north as compared with those in the south. The choice of cultivars changes little from east to west.

Historically, indeterminate type soybeans have been the choice of farmers located north of 37° north latitude and the determinate type of those south of this latitude. The popularity of the determinate type in the south is based on shorter stature and resistance to lodging. In that area, indeterminate cultivars of comparable maturity tend to grow tall and lodge. In recent years, soybean breeders in northern growing areas have released determinate type cultivars which are more resistant to lodging than the indeterminates but are equal in yielding ability.

Other production practices are similar from north to south and from east to west.

PLANTING DATE

The response of soybeans to photoperiod largely dictates when soybeans are planted. In the cooler north, where soybeans and maize are the major crops, soil temperature and day length requirements occur at about the same time and soybeans are planted during the month of May and early June. Because planting date affects maize yields to a greater degree than soybeans, farmers tend to finish planting maize before they begin to plant soybeans. However, date of planting studies in the north show that the yield of soybeans begins to decrease when planting is delayed past early May. In the southern U.S. soil temperature warms to that required to germinate soybeans long before the day length is correct. Therefore, the time of planting in the south is about the same as in the north. The bulk of the crop is planted during the month of May, weather permitting. The effect of date of planting is shown in Tables 1 and 2.

Table 1. Effect of planting date on yield for northern U.S. growing areas, kg/ha

Cultivar	May 10	May 25	June 10
Amsoy 71	3,199	2,869	2,278
Wayne	3,320	2,923	2,392
Williams	3,427	2,863	2,251

Source: Ohio State University Cooperative Extension Service Agronomy Mimeo 221. 1978.

RATE OF PLANTING

The recommended rate of planting varies little from east to west or from north to south. Recommended population is shown in Table 3. The larger number is used for lodging-resistant cultivars, and the smaller population for cultivars that have a tendency to lodge under good growing conditions.

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Table 2. Effect of planting date on the average yield of three soybean cultivars for southern U.S. growing areas, kg/ha

April 15	May 1	May 15	June 1	June 15	July 1	July 15
2,757	2,892	2,959	3,093	2,892	2,824	2,488

Source: Arkansas Farm Research 28(2):8. 1979.

Table 3. Recommended population for soybean plantings in the U.S.

Row width (cm)	Optimum population, plants/linear meter of row	Plants/ha
91	23 to 30	252,747 to 329,670
76	20 to 26	263,160 to 342,108
51	16 to 20	313,728 to 392,160
25 or less	7 to 13	280,000 to 528,000

Source: Scott, W. O., and S. R. Aldrich. 1970. Modern Soybean Production. S & A Publications, Champaign, Illinois.

ROW WIDTH

Research in the northern production area shows that soybeans planted in rows less than 76 cm wide produce more than those planted in rows more than 76 cm if weeds are controlled. In the southern production area, where the weather is warm, soybeans tend to grow taller and faster. The advantages of narrow rows are not as consistent in the south as in the north. However, there has been a trend to narrow rows nationwide (Table 4). The major reason for the increased interest in narrow rows is better weed control.

Table 4. Average row width for soybeans

State	Average row width (cm) 1978	1981
Arkansas	93.7	86.1
Illinois	85.0	70.6
Louisiana	93.2	89.7

Source: United States Department of Agriculture. 1981. Crop production. USDA Crop Reporting Board.

WEED CONTROL

Specific chemicals or herbicides will not be discussed, but most of the soybeans grown in the U.S. are treated with at least one herbicide. The best weed control program involves both mechanical and chemical methods.

INOCULATION

Many soybean growers inoculate the seed with *Rhizobium* before planting. A newer technique involves putting the inoculant in the row with the seeds. Research throughout the soybean growing area of the U.S. shows that soybean yields are seldom increased by inoculating seeds or soil in fields where a well-nodulated crop of soybeans has been grown within the last three to five years. If soybeans have not been grown in a field within the last five years, inoculation should be practiced.

PLANTING EQUIPMENT

Most of the soybeans in the U.S. are planted with row crop planters, which also are used for other crops such as maize.

There is increasing interest in the use of a small-grain drill which plants very narrow rows. The width of row with these planters varies from 15 to 25 cm. The interest in planting soybeans in narrow rows with the drill coincides with the development of herbicides that can control both broadleaf and narrowleaf weeds after soybeans have emerged. Prior to the development of these herbicides, weed control after emergence was done mechanically or by hand.

Another planting method gaining popularity is skip row planting. Planters sow soybeans in rows 38 to 51 cm wide, and skip a row where the tractor wheels run, making those rows either 76 or 102 cm. This method accomodates mechanical cultivation with tractor-mounted equipment.

South of 40° north latitude soybeans commonly are planted in small-grain fields after the grain is harvested. In some cases a conventional seedbed is prepared, but more commonly soybeans are planted in the stubble with an implement called a "zero till planter." In this method a contact herbicide is applied to weeds that have already emerged in stubble, and preemergence herbicides are applied for weeds that emerge after soybeans are planted.

MECHANICAL CULTIVATION

Except for soybeans planted with a zero till planter, most soybeans in the U.S. are cultivated with a rotary hoe. This cultivation takes place soon after soybeans emerge and before many of the weeds have emerged. This implement also is used to improve the emergence of soybeans when a soil crust is formed following a heavy rain. In addition to the rotary hoe, soybeans planted with a row crop planter usually are cultivated at least once with a shovel cultivator.

HARVESTING

Essentially all soybeans grown in the U.S. are harvested with combines and sold for processing. Some soybean growers market their crop at harvest time, others store it on the farm or in commercial storage.

Interaction of Soybean Cultural Practices and Yield

CHANG YAO-ZHONG

From 1976 to 1980, experiments were conducted at Heilongjiang Academy of Agricultural Sciences, Harbin, on the relationship between yield and cultural practices in soybeans. Heilongjiang Province is one of the major soybean production regions in China and accounts for more than 25% of the total hectarage and yield. However, yields are low compared with world production averages.

Experimental plots had black, fertile soil with 2.5-2.8% organic matter; 0.5-0.75% nitrogen; 5.5-7.5 mg hydrolytic nitrogen per 100 g soil; 0.08-0.1% total phosphorus; 10-15 mg/100 g soil available phosphorus; 2.5-2.8% potassium; and 19-21 mg/100 g soil available potassium. Soybeans were sown after wheat. The field was plowed to 20 cm, then harrowed and ridged. Row spacing was 70 cm. Planting density varied according to cultivar. Average population was 20-25 plants per square meter, but was less than 15 and greater than 30 in some plots. Planting normally occurred in late April or early May.

Before fall plowing, 37,500-52,500 kg/ha of farmyard manure or peat mixed with 225-375 kg/ha of calcium superphosphate was broadcast. Before spring planting, 15,000-22,500 kg/ha decomposed animal manure was applied to the ridges split by the lister and covered with soil, and 375 kg/ha calcium superphosphate or 225 kg/ha diammonia phosphate was applied as a top dressing during the period from seedling to branching. Plots were cultivated and weeded three times, and roots were covered with soil during cultivation to prevent lodging. Fields were irrigated when soil moisture dropped to less than 65% of the maximum water-retaining capacity, especially during the later period of growth.

RESULTS AND ANALYSIS

Under normal conditions, yield was calculated by: plants per unit area x average pods per seed (Chang Yao-zhong et al., 1978; Dong Zuan et al., 1979). Table 1 shows the yield per cultivar. More pods per square meter results in higher yields, but yield does not increase when there is low seed/pod ratio and light weight per 100 seeds.

Under normal conditions, a large leaf-area index (LAI) results in a high yield (Shanghai Institute of Plant Physiology, 1976). However, with adequate fertilizer and water, excessive vegetative growth can cause shading and reduce yield (Chang Yao-zhong, 1981). When the soybean yield exceeds 3,000 kg/ha, an LAI of 5 to 6 is necessary for optimum production (Table 2). The maximum LAI normally occurs between late-pod set and early-pod fill. The rate of dry matter accumulation (DMA) decreases because plant growth is concentrated in the pods, and the net photosynthesis rate (NPR) is low. In high yield cultivation it is important to control excessive increase in the LAI and to promote a steady growth rate in the plant. This prevents slow accumulation of DMA and maintains a higher NPR.

Different cultivars have different photosynthetic rates. The higher the photosynthetic rate, the higher the yield (Table 3). For example, the photosynthetic rate of Ha 76-6296 is 12.2-16.8% higher than that of Heinong 26, and the yield is 13% greater.

Soil with a high organic matter and nutrient content, especially phosphorus, will produce larger yields (Table 4).

Data from 1979 and 1980 indicate that the water needs of soybeans vary with growth period. Water requirement per plant for 24 hours was: 200 g during flowering; 350 g between flowering and pod setting; and 300 g at pod fill. Soybean plants need more moisture during the later growing stages. Overall, a soybean plant needs 500 g of water to form 1 g of dry matter. Experiments on time of irrigation show that irrigation during the later growing stages has the best effect on yield (Table 5). Adequate moisture at all stages of growth can increase yield by 24% to 35%.

Narrow row, dense planting insures proper spacing and allows better utilization

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Table 1. Yields and yield components of different cultivars at Harbin, 1976-1980

Year	Cultivar	Pods/m^2	Seeds/m^2	Weight (g/ 100 seeds)	Yield (kg/ha)
1976	Dongnong 72-806	520	1,545	21.0	3,262
	Heinong 26	595	1,552	19.8	3,735
1977	Ha 76-6296	608	1,266	23.4	3,465
	Ha 76-6045	494	1,343	24.0	3,405
	Ha 76-6012	668	1,462	16.7	2,640
1978	Heinong 26	668	1,550	17.6	2,955
	Ha 76-6045	446	1,123	20.9	2,475
	Dongnong 72-806	460	1,462	16.7	2,805
1979	Heinong 26 (by drilling)	687	1,772	18.8	2,902
	Heinong 26 (by hill-dropping)	743	1,774	18.9	3,067
	Dongnong 72-806 (by drilling)	571	1,356	18.9	2,805
	Dongnong 72-806 (by hill-dropping)	553	1,409	18.9	3,142
1980	Heinong 26 (by drilling)	693	1,611	15.1	2,647
	Heinong 26 (by hill-dropping)	694	1,806	15.6	2,745

Table 2. Yield and leaf area index measurements at different stages of growth at Harbin, 1976-1980

Year	Yield (kg/ha)	Leaf area index			
		Flowering stage	Pod setting stage	Pod filling stage	Leaf-yellowing stage
1976	3,263	5.00	6.00	4.83	4.42
	3,135	3.67	4.37	4.92	4.11
1977	3,405	3.80	6.18	4.62	4.53
	2,483	4.50	6.82	3.86	3.77
1978	2,805	1.67	3.05	4.53	3.40
	2,955	2.04	3.60	6.00	4.76
1979	2,805	1.78	3.36	3.39	2.16
	3,143	2.52	4.89	5.62	2.72
1980	2,820	2.17	3.33	4.04	1.65
	2,573	1.64	3.03	3.62	1.84

Table 3. Relationship between net photosynthesis rate (mg CO_2 dm^{-2} hr^{-1}) and yields of different cultivars, Harbin, 1977

Cultivar	Measured on July 27		Measured on August 12		Yield	
	NPR	% of Heinong 26	NPR	% of Heinong 26	Kg/ha	% of Heinong 26
Ha 76-6296	25.34	112.2	27.50	116.8	3,465	113.0
Ha 76-6041	20.29	90.2	--	--	2,580	84.1
Ha 76-6012	17.12	76.2	22.35	94.9	2,640	86.1
Heinong 26	22.49	100.0	23.55	100.0	3,067	100.0

Table 4. Relationship between soil fertility and soybean yield, Siuhua, 1976

Yield levels (kg/ha)	Total nitrogen (%)	Hydrolytic nitrogen (mg/100 g soil)	Total phosphorus (%)	Available phosphorus (mg/100 g soil)	Total potassium (%)	Organic matter (%)
3,000-3,750	0.238	6.58	0.161	20.93	2.60	4.68
2,625-3,000	0.196	6.29	0.122	7.43	2.51	3.71
2,250-2,625	0.192	5.98	0.121	6.46	2.51	3.69
1,875-2,250	0.164	4.73	0.104	4.69	2.50	3.27

Table 5. Relationship between irrigation timing and soybean yields of Heinong 26 at Harbin, 1979-1980

Year	Irrigation timing	Pods/ plant	Seeds/ plant	Aborted pods (%)	Weight (g/100 seeds)	Yield	
						Kg/ha	% of check
1979	Branching stage	24.6	----	2.3	16.4	2,424	104.1
	Flowering and pod setting stage	32.5	----	2.1	16.5	2,629	112.9
	Pod filling stage	31.7	----	1.3	18.1	2,893	124.2
	All growing stages	36.6	----	1.0	20.0	2,900	124.5
	Check, no irrigation	31.6	----	1.4	15.0	2,329	100.0
1980	Flowering stage	25.1	64.8	0.8	15.7	2,131	109.4
	Pod setting stage	28.2	72.4	0.9	16.1	2,477	127.4
	Flowering and pod setting stage	28.5	73.9	0.7	16.9	2,597	133.8
	Flowering and pod filling stage	27.4	67.9	0.8	17.4	2,627	135.3
	Check, no irrigation	23.3	54.8	1.1	14.0	1,941	100.0

of sunlight and farmland. This method increased yield by 7.4% to 13.8% over wide row planting (Table 6), and is gaining popularity. Equidistant, hill-drop planting also insures proper plant density and better utilization of sunlight (Chang Yao-zhong et al., 1978; Shannon et al., 1971). Data from experiments at the Academy and in eight coun-

Table 6. Effect of narrow-row planting on yields and yield components, 1973 and 1977

Year	Cultivar	Planting pattern	Pods/ plant	Seeds/ plant	Weight (g/ 100 seeds)	Yield Kg/ha	Yield % of wide row
1973	Suinong-3	Narrow row (30 cm)	21.5	55.2	17.8	2,715	113.8
		Wide row (60 cm)	20.3	47.9	17.5	2,385	100.0
1977	Ha 76-6043	Narrow row (50 cm)	32.8	93.3	17.5	3,360	107.4
		Wide row (70 cm)	31.6	91.0	17.4	3,128	100.0

Table 7. Effect of equidistant hill drop planting on yield and its components, Heilongjiang, 1979-1980

Year	Place	Cultivar	Planting pattern	Pods/ plant	Seeds/ plant	Weight (g/100 seeds)	Yield Kg/ha	Yield % of drilling
1979	Harbin	Dongnong 72-806	3 plants per hill	22.1	56.4	18.9	3,143	112.0
			Single drilling	22.8	54.2	18.9	2,805	100.0
1980	Bin County	Heinong-26	3 plants per hill	25.2	63.4	14.4	2,678	114.4
			Double drilling	23.3	58.8	14.5	2,340	100.0
1980	Yian County	Kejiao 69-053	4 plants per hill	31.9	88.9	14.0	3,003	112.1
			Double drilling	28.5	79.7	13.4	2,680	100.0

ties in Heilongjiang showed a yield increase of 4% to 18% (Table 7). Compared with the drill planting method, the hill method inhibits seedling growth, but after flowering it is favorable to light and ventilation. Also, it prolongs the closing of the canopy and reduces the yellowing of the leaves underneath. Canopy closing can be delayed for 6 to 8 days.

IN CONCLUSION

Seedling vigor is related closely to soybean yield. In Heilongjiang Province, the spring is dry and cold, with low soil temperatures. It is important to promote seedling growth to insure successful flowering and pod setting. Better soil preparation, more fertilizer, and careful management are the basis for good stand establishment, vigorous growth, and stable and high yields (Table 8). Yields can be increased by 14.2% to 20.8%.

Planting density affects yield. Table 9 shows that a density of 25 plants per square meter yields 15.1% more than 15 plants per square meter, and 9.4% more than 35 plants per square meter. Fertilizer and water needs and plant density must be adapted to the cultivar.

Table 8. Relationship between seedling vigor and soybean yield, Harbin, 1976

Cultivar	Vigor rating	Emergence date	Growth at seedling stage (June 24)			Yield	
			Plant height (cm)	LAI	DMA (g/m)	Kg/ha	% of single-plant branched
Dongnong 72-806	Very lush	May 26	12.1	0.38	27.9	3,120	120.1
Heinong 26	Lush	May 27	10.3	0.44	31.4	3,139	120.8
Branched Soybean[a]	Average	May 27	9.8	0.15	11.5	2,978	114.6
Branched Soybean[b]	Poor	May 27	9.9	0.06	3.7	2,599	100.0

[a]Double plants per hill.
[b]Single plant per hill.

Table 9. Yield and yield components of Dongnong 72-806 at different plant densities, Harbin, 1979

Density (plants/m^2)	Branches per plant	Maximum LAI (pod filling stage)	Pods/plant			Seeds/plant			Weight (g/100 seeds)	Yield	
			Main stem	Branch	Total	Main stem	Branch	Total		Kg/ha	% change from 25 plants/m^2
35	0.10	5.52	15.26	0.17	15.43	37.57	0.43	38.00	18.90	2,872	-9
15	1.10	3.39	29.20	5.40	34.60	73.80	8.27	82.07	18.90	2,730	-15
25	0.50	5.62	20.76	1.72	22.48	53.24	3.56	56.80	18.90	3,142	0

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Current Status of Plant Protection for Soybeans in the United States

L. DALE NEWSOM

Pest-induced stress is a major component of the barrier to increased soybean yield in the U.S.

Some background information is necessary for an appreciation of the complexity and severity of pest problems in the U.S. Soybeans were first planted in Pennsylvania (Piper and Morse, 1923). After 1940 there was a huge expansion in hectarage in response to increased demand for oil and protein. After World War II, soybean cultivation expanded into areas subject to severe pest attack. The area planted to soybeans increased from 5.6 million hectares to approximately 27.6 million hectares in 1980. This area is bounded by the 98° meridian to the west, Canada to the north, the Atlantic Ocean to the east, and the Gulf of Mexico to the south, roughly between 28° and 46° north latitude. More than 90% of total U.S. production is in 22 states, 12 states in the interior plains region and 10 states in the coastal plains region. It is in the latter area that expansion in soybean production has been most dramatic, with a 12-fold increase from 762,000 hectares in 1950 to 9,746,000 hectares in 1980 (Table 1). Pest problems of greater diversity and severity occur in the coastal plains region than anywhere else in the U.S.

The heterogeneity of ecological conditions and soybean cropping patterns provides large numbers of ecological niches which are important determinants of qualitative and quantitative diversity of pests associated with soybeans. Each has unique problems as well as those shared with some, or all, of the other agroecosystems (Kogan, 1979). The filling of vacant niches accounts for the more than five-fold increase in numbers of soybean pests since Piper and Morse (1923) published their book. They listed eight species of pathogens, 12 of insects, and two of nematodes. We can expect further increases in the numbers of important pest species of soybeans during the next several decades. Weather conditions and proximity of the coastal plains region to sources of exotic pests in Central America, South America, and Mexico also favor development of new soybean pests.

There are four classes of major pests of soybeans in the U.S., ranked in order of importance: weeds, nematodes, pathogenic diseases, and insects (Table 2). The order is based on losses in quantity and quality and on costs of control. Many contend that losses to weeds exceed those of all other pests combined. Considerable disagreement exists on the ranking for the other three classes.

MAGNITUDE OF LOSSES TO SOYBEAN PESTS IN THE U.S.

Soybeans are attacked by, and subjected to competition with, one or more species of important pests from planting time to harvest. All plant parts are attacked. Often more than one species of each pest category attack the plant simultaneously.

Economic injury thresholds have been established for a few of the major pest species. Except for nematodes, nothing has been done toward developing economic thresholds for pests that attack below-ground parts of the plant. Research aimed at developing economic injury thresholds for complexes of pest species is just beginning.

Accurate estimates of crop losses to pests plus costs of control measures are difficult to obtain. Those available are "educated guesses" made by research and extension personnel.

Estimates of losses to diseases, including nematodes, were prepared for the 1975 and 1976 crops by a Disease Loss Committee of the Southern Soybean Disease Workers for an area composed mostly of the coastal plains states (Anonymous, 1977; Anonymous, 1978a) (Table 3). The average estimated loss for each year was 20%, and ranged from 5.4% to 49% in the various states. Usual estimates of losses to pests of soybeans are more conservative, although there is little reason to believe that they are any more accurate. They usually range from 20% to 30%. Data from Ennis (1976) and

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Table 1. Changes in area planted to soybeans in two major producing regions of the U.S., 1950-1980[a]

Region	Area, in 1,000 ha			
	1950	1960	1970	1980
Interior plains states				
Illinois	1,614	2,013	2,752	3,743
Indiana	669	977	1,327	1,773
Iowa	781	1,052	2,299	3,347
Kansas	161	237	376	587
Michigan	46	89	202	384
Minnesota	465	846	1,226	1,926
Nebraska	20	66	329	716
North Dakota	17	71	73	81
Ohio	441	607	1,032	1,522
South Dakota	28	40	100	312
Wisconsin	13	39	62	134
TOTAL	4,744	6,986	11,180	17,763
Coastal plains states				
Alabama	30	54	243	850
Arkansas	235	975	1,781	1,760
Georgia	11	30	192	866
Kentucky	51	81	214	648
Louisiana	15	87	683	1,356
Mississippi	145	371	1,044	1,558
North Carolina	120	221	351	781
South Carolina	25	166	409	648
Tennessee	68	159	465	1,032
Virginia	62	130	137	247
TOTAL	762	2,274	5,519	9,746

[a]Source: Economic Research Service, U.S. Department of Agriculture.

McWhorter and Anderson (1981) plus estimates of the costs of chemicals used by farmers in 1975 (Soybean Digest Gold Book, 1976) (Table 4) were used to estimate the losses to all pests of soybeans in the U.S. during 1980 (Table 5). The estimates are conservative: US$1.6 billion, about 12% of the value of the 1980 crop. If less conservative estimates had been used, the 20% loss to pathogens and nematodes alone, for example, would have amounted to about US$2.8 billion.

Workers responsible for managing soybean pests in the U.S. have accomplished much. Nevertheless, unacceptably high losses to pests continue to occur. More research is needed before reliable estimates can be made.

STATUS OF PEST PROBLEMS AND TECHNOLOGY FOR THEIR CONTROL

Weeds

Sixty species are considered major pests (McWhorter and Patterson, 1979) (Table 2). However, the pest status of weeds is constantly changing. The underlying reason for most of the change is altered production methods, such as reduction in the amount of mechanical cultivation; increase in no-tillage, reduced-tillage, and double cropping soybeans and small grains; increase in broadcasting seed, planting with grain drills, and planting in reduced row spacings; change in rotations; use of similar kinds of herbicides for relatively long periods of time; development of herbicide resistant biotypes; and introduction and colonization of species into areas where they did not previously occur.

The accelerating rate of "ecological shifts" in weed species creates new niches, and allows development of new pest species or changes in pest status of established species. Recent changes in production have been made in response to decreasing availability of labor, increasing costs of fossil fuels, and increasing awareness of the problem of soil erosion. They have resulted in decreased tillage, increased dependence on herbicides, and changes in weed flora (Ayers, 1975; Buchanan et al., 1975; Burnside, 1978; Gebhart, 1981; Sanford et al., 1973; and Wax et al., 1977).

Problems of weed control in the coastal plains are more severe than in the interior

Table 2. Species of soybean pests currently considered to be of economic importance in the U.S.

PATHOGENS (Sinclair, 1982)

Bacteria
- *Pseudomonas syringae* pv. *glycinea*
- *Xanthomonas campestris* pv. *phaseoli*

Fungi
- *Alternaria* spp.
- *Calonectria crotalariae*
- *Cercospora kikuchii*
- *Cercospora sojina*
- *Colletotrichum dematium* var. *truncatum*
- *Corynespora cassiicola*
- *Diaporthe phaseolorum* var. *caulivora*
- *Diaporthe phaseolorum* var. *sojae*[a]
- *Fusarium* spp.
- *Macrophomina phaseolina*
- *Microsphaera diffusa*
- *Peronospora manshurica*
- *Phialophora gregata*
- *Phomopsis* spp.
- *Phyllosticta sojaecola*
- *Phytophthora megasperma* f. sp. *glycines*
- *Phythium* spp.
- *Rhizoctonia solani*
- *Sclerotinia sclerotiorum*
- *Sclerotium rolfsii*
- *Septoria glycines*
- *Thielaviopsis basicola*

Viruses
- Bean pod mottle virus
- Cowpea chlorotic mottle virus
- Soybean mosaic virus
- Tobacco ringspot virus (bud blight)
- Tobacco streak virus (Brazilian bud blight)
- Yellow mosaic virus

Nematodes
- *Belonolaimus* spp.
- *Heterodera glycines*
- *Hoplolaimus* spp.
- *Meloidogyne* spp.
- *Pratylenchus* spp.
- *Rotylenchulus reniformis*

INSECTS (Kogan, 1979; Newsom et al., 1980)

- *Acrosternum hilare*
- *Agrotis ipsilon*
- *Anticarsia gemmatalis*
- *Cerotoma trifurcata*
- *Colaspis* spp.
- *Dectes texana*
- *Delia platura*
- *Diabrotica balteata*
- *Elasmopalpus lignosellus*
- *Epargyraeus clarus*
- *Epicauta* spp.
- *Epilachna varivestis*
- *Estigmene acrea*
- *Euschistus servus*
- *Euschistus tristigmus*
- *Heliothis virescens*
- *Heliothis zea*
- *Melanoplus* spp.
- *Nezara viridula*
- *Plathypena scabra*
- *Pseudoplusia includens*
- *Rivellia quadrifasciata*
- *Sericothrips variabilis*
- *Spissistilus festinus*
- *Spodoptera frugiperda*
- *Spodoptera exigua*
- *Tetranychus* spp.
- *Vanessa cardui*

WEEDS (McWhorter and Patterson, 1979; Slife, 1979)

- *Abutilon theophrasti*
- *Agropyron repens*[b]
- *Amaranthus* spp.[b]
- *Ambrosia artemisiifolia*
- *Ambrosia trifida*
- *Apocynum cannabinum*
- *Asclepias syriaca*
- *Brachiaria platyphylla*
- *Brassica haber* var. *pinnatifida*
- *Brunnichia cirrhosa*
- *Campsis radicans*
- *Cenchrus* spp.
- *Cassia obtusifolia*
- *Chenopoduim album*[b]
- *Cirsium arvense*
- *Convolulus arvensis*
- *Crotolaria* spp.
- *Cyperus esculentus*
- *Cyperus rotundus*
- *Datura stramonium*
- *Digitaria* spp.
- *Echinochloa crusgalli*
- *Elusine indica*
- *Helianthus annus*
- *Ipomoea* spp.
- *Muhlenbergia frondosa*
- *Panicum dicotomiflorum*[b]
- *Panicum texanum*[b]
- *Pologynum* spp.
- *Richardia scabra*
- *Sesbania exaltata*
- *Setaria faberi*[b]
- *Setaria lutescens*[b]
- *Setaria viridis*[b]
- *Sida spinosa*
- *Solanum carolinense*
- *Sorghum bicolor*
- *Sorghum halepense*[b]
- *Xanthium pensylvanicum*[b]

[a]Schnitthenner and Kmetz (1979) have pointed out that an undescribed species of *Phomopsis* is the most prevalent seed decaying organism of soybeans in Ohio, and that it is often confused with *Diaporthe* spp.
[b]Considered the most important (compiled by Crops and Soils Magazine, 1970).

Table 3. Disease loss estimates in relation to yield of soybeans in coastal plains states during 1975 and 1976

State	1975 Estimated loss[a] (%)	1975 Yield[b] (kg/ha)	1976 Estimated loss[a] (%)	1976 Yield[b] (kg/ha)
Alabama	---	---	26.5	1,617
Arkansas	25.5	1,617	28.0	1,213
Florida	30.0	1,617	30.0	1,752
Georgia	5.4	1,685	7.0	1,584
Kentucky	12.0	1,786	14.1	1,786
Louisiana	24.5	1,617	33.0	1,752
Maryland	10.2	1,887	10.6	1,685
Mississippi	14.5	1,483	8.6	1,482
North Carolina	15.2	1,550	10.4	1,449
Oklahoma	24.5	1,550	26.9	1,483
South Carolina	18.6	1,483	18.0	1,213
Tennessee	17.7	1,651	23.2	1,516
Texas	16.0	1,651	15.4	1,685
Virginia	49.0	1,685	21.0	1,685
AVERAGE	20.2	1,636	19.5	1,565

[a]Source: Estimated percent loss from Southern Soybean Disease Workers, Soybean Disease Loss Estimate Committee Reports (includes nematodes). Plant Disease Reporter 61:42, 1977; 62:539-540, 1978.

[b]Source: Economic Research Service, U.S. Department of Agriculture.

Table 4. Chemical costs for soybean production in two major producing regions of the U.S. in 1975 and 1980

Region	Estimated cost/ha 1975[a]	Estimated cost/ha 1980[b]
Interior plains states		
Illinois	$ 18.36	$ 26.91
Indiana	17.32	27.91
Iowa	21.15	34.09
Kansas	15.99	25.76
Michigan	14.23	22.91
Minnesota	15.96	25.72
Missouri	18.66	30.05
Nebraska	15.96	25.72
Ohio	18.83	30.33
South Dakota	11.32	18.27
Wisconsin	13.62	21.92
AVERAGE	16.26	26.33
Coastal plains states		
Alabama	$ 32.47	$ 52.29
Arkansas	26.17	42.15
Georgia	32.84	45.25
Kentucky	32.84	52.88
Louisiana	33.33	53.68
Mississippi	18.73	30.09
North Carolina	34.64	55.78
South Carolina	39.07	62.93
Tennessee	17.99	28.99
Virginia	46.78	75.35
AVERAGE	31.01	49.94

[a]Source: Soybean Digest Gold Book. 36:22, 1976.

[b]Estimated from 1975 data allowing for a 10% annual inflation rate.

Table 5. Estimated losses to soybean pests and costs of protection in the U.S., 1980

Assumptions	Cost (US$1 million)
20% loss in yield to all pests[a]	
12.6% to weeds	$ 174.2
3.0% to nematodes	41.5
2.6% to pathogen	35.9
1.8% to insects	24.7
Cost of chemicals at $38.06/ha,80% of hectarage treated[b]	682.3
Cost of cultural practices for weed control[c]	
Disk at US$5.31/ha	145.8
Disk and incorporate herbicide at $7.39/ha	202.9
Apply herbicide at $2.10/ha	57.7
Cultivate early at $5.78/ha	158.7
Cultivate late at $3.85/ha	105.7
TOTAL	$1,629.6

[a]Source: Ennis, 1976.
[b]Source: Soybean Digest Gold Book, 36:22, 1976, for cost of chemicals in 1975; 1980 cost estimated by allowing for a 10% annual inflation rate; estimate of area treated from McWhorter and Patterson, 1979.
[c]Source: McWhorter and Patterson, 1981, 1980 cost estimated from 1972 data by allowing for a 10% annual inflation rate.

plains. In the interior plains, perennial species are unimportant and summer annuals are a more serious problem (Wax, 1973; Slife, 1979). In the coastal plains, there is a greater variety of both perennial and annual species and favorable growing conditions are longer. Many species which are severe in the coastal plains developed as a result of ecological shifts (Franz, 1979).

In spite of the differences in species and severity of infestations, similar weed control systems developed in the two regions. Both are dependent upon tillage practices, crop rotation, and herbicides. Eighty to 90% of the area planted to soybeans receives herbicide treatment each year.

Tillage is used extensively before planting to destroy weed growth. One or more diskings, harrowings, and use of a rotary hoe may be employed, depending upon severity of the weed problem. One or more row cultivations may be made where conventional row widths are used.

More attention is being given to crop rotations than a decade ago, particularly in the interior plains. Rotations have become essential to handling problems associated with resistant biotypes and ecological shifts. Throughout both regions experimental results and grower experience generally support Gebhart's (1981) conclusions that cultivation plus herbicide application gives more effective weed control and better yields than other combinations of practices.

Herbicide applications may consist of combinations of preplant soil incorporation, preemergence at or immediately after planting, and postemergence overtop or post-directed beneath the soybean canopy. Preplant and preemergence applications may consist of a mix of two herbicides, one for control of grasses and the other for broadleaf species. Preplant and preemergence applications usually are so effective that postemergence applications rarely are needed in the interior plains (Slife, 1979).

Compared with insects, herbicide-resistant biotypes developed slowly in weed flora. Many weed control specialists doubted that such development would occur and were reluctant to accept early reports of the appearance of herbicide-resistant biotypes. It occurs in at least half of the "ten worst weeds" of soybeans, namely, *Amaranthus retroflexus, Chenopodium alba, Echinochloa crusgalli, Setaria* spp., and *Sorghum halepense* (Anonymous, 1970), and resistance to herbicides occurs in a large number of species (Hensley, 1981; Jensen et al., 1977; McWhorter, 1971; Oliver and Schreiber, 1971; Roche and Muzik, 1964; Santelman and Meade, 1961; and Thompson et al., 1974).

In general, rotation is used less, preplant tillage more, and postemergence applications of herbicides considerably more in

the coastal plains than in the interior plains.

Improved weed control has become available with the development of more selective herbicides. There is general recognition that routine preplant and preemergence applications of herbicides should be avoided. This will allow growers to develop control systems for weeds that are based on the principles of integrated pest management (IPM). IPM is the use of appropriate cultural, biological, and chemical control measures to assure favorable economic, environmental, and social results.

Weed control specialists are aware of the need to develop IPM systems for weeds. Economic injury thresholds have been developed for several species instead of holding the philosophy of "one weed per hectare is too many" that has been established for some of the most important weed pests. Research has begun on the even more important subject of economic injury thresholds for pest complexes, but this needs to be greatly accelerated (Barrentine and Oliver, 1977; Coble and Ritter, 1978; Coble et al., 1981; Eaton et al., 1973; Hagood et al., 1981; Knake and Slife, 1962; McWhorter and Patterson, 1979; McWhorter and Anderson, 1981; Oliver, 1979; Schultz and Burnside, 1979; Staniforth, 1965; and Thurlow and Buchanan, 1972).

There is need for developing new weed control strategies. In systems highly dependent upon use of chemicals, selective pressures on populations are so intense that serious problems of herbicide-resistant biotypes are certain to develop. Biological control and allelopathy appear to be promising fields for expanded research efforts (Kirkpatrick et al., 1982; and Templeton et al., 1979).

Nematodes

Nematode species currently considered to be of major importance as soybean pests are: *Meloidogyne* spp., *Heterodera glycines*, *Rotylenchulus reniformis*, *Pratylenchulus* spp., *Hoplolaimus* spp., *Belonolaimus* spp., and *Helicotylenchus* spp. (Sinclair, 1982; Caviness and Riggs, 1976). The number of species has not increased as much as other pests since 1923. Many species are associated with soybeans in the U.S. (Edwards, 1976), but their pest status remains uncertain.

Soybean losses attributed to nematodes vary from 3% (Ennis, 1976) to 10% (Feldmesser et al., 1971) of the total U.S. crop. Estimated losses attributed to *Heterodera glycines* and *Meloidogyne* spp. in the coastal plains region in 1975 were 7.5% (Anonymous, 1977). These estimates do not include costs of treatments. Regardless of the accuracy of estimated losses from nematode injury, direct losses of production are substantial.

In addition to yield effects, nematodes interact with various species of fungi to produce injury levels exceeding the sums of their individual effects. Edwards (1976) found five specific examples of interactions between pathogens and nematodes on soybeans involving *Rhizoctonia solani*, *Phytophthora megasperma* f. sp. *glycines*, *Fusarium oxysporum*, *Microphomina phaseolina*, and "seedling diseases." The nematodes involved were *Meloidogyne* spp., *Heterodera glycines*, and *Pratylenchus* spp.

Nematodes also interact with *Rhizobium* and can affect nitrogen fixation. Effects reported have been highly variable, however (Baldwin et al., 1979; Lehman et al., 1971). Research is needed to clarify the nematode relationship to nitrogen fixing capacity of soybeans.

Research on the development of economic injury thresholds has been small and results extremely variable. Kimloch (1980) predicted a yield loss of 6.3, 12.6, 25.1, and 35.5 kg/ha for each juvenile *Meloidogyne incognita* recovered per 10 cm^3 of soil taken at 150, 100, 50, and 25 days before planting, respectively. On the other hand, Riggs et al. (1980) reported no correlation between numbers of *H. glycines* cysts and yields. Such conflicting results illustrate the difficulty of establishing useful economic injury levels and of obtaining accurate loss estimates. The following problems are involved: extreme within-field variability of populations (Hartwig et al., 1982); extrapolation of miniplot data to field situations; conducting experiments in severe problem areas that are often not representative of the field in which the experiments are located, much less the surrounding area; use of nematicides that often have insecticidal activity and may have fungicidal activity as well (Kittle and Gray, 1982); and possible interactions with other nematode species known to be soybean pests (Ross, 1964) or with species whose pest status has not been established.

Extensive programs for nematode control have been inaugurated by extension personnel in some states, based on evaluations of soil samples and previous history of individual fields. Based on such information obtained, the following kinds of recommendations are made for control of *H. glycines*: Plant a nonhost crop such as maize or grain sorghum the first year, followed by a resistant soybean cultivar the second year, and a susceptible cultivar the third year (Riggs et al.,

1980); plant cotton, grain sorghum, or maize the first year in infested fields, a Race 3-resistant cultivar the second year, and a Race 3- and 4-resistant cultivar the third year; before the fourth year submit soil samples to an extension plant pathologist to determine if nematode and egg populations are low enough to allow planting of a susceptible cultivar the fourth year with or without application of a nematicide (Taylor, 1981); and if soil tests do not indicate damaging levels of Race 4, plant a Race 3-resistant cultivar the first year, the second year plant a Race 3- and 4-resistant cultivar, and before planting the third year submit soil samples to an extension pathologist for nematode assay to ascertain whether or not to plant a susceptible cultivar with or without fumigation (Taylor, 1981).

Systems of this sort are based on sound concepts of IPM. A possible weakness is that of the accuracy and applicability of the methods used, and the lack of responsibly developed economic injury thresholds for population assessment. Systems of this sort have an added advantage of helping to control other nematode pest species, particularly *Meloidogyne* spp. and *Rotylenchulus reniformis*.

Use of cultivar resistance is an effective control of *H. glycines* and *Meloidogyne* spp. However, cultivars resistant to one species may not be resistant to others; and nematodes, especially *H. glycines*, have the ability to overcome resistance by development of new races (Young, 1982).

Contrary to Young's (1982) experience with *H. glycines*, Hartwig et al. (1982) reported results of an experiment in which soybeans were grown continuously for nine years in a *H. glycines*-infested area. They suggested the possible involvement of a natural control agent as an explanation of the results obtained.

Greatly expanded research is needed to determine the pest status of nematode species associated with soybeans but which are not now considered to be important pests. An equal, or possibly more pressing, need is to establish accurate economic injury thresholds for species known to be pests.

Pathogens

The number of pathogens of major significance to soybean production has increased about four-fold since Piper and Morse (1923) listed the soybean diseases known for the U.S. (Table 3) (Sinclair, 1982). Estimates of the impact of disease agents on soybean production range from about 3% (Ennis, 1976) to as much as 30% of the total crop. A reasonable estimate is 12% (Anonymous, 1977) for the coastal plains region, where both incidence and severity of soybean diseases exceed that in other regions of the U.S. Assuming an average loss of 10%, the 1980 crop loss would be approximately 49.5 million metric tons. Loss of production at average prices for the year would amount to US$1.4 billion.

Use of resistant cultivars, rotation, plowing under crop debris, and planting pathogen-free seeds have been successful for control of most of the important diseases of soybeans. Cultivar resistance has been especially effective, probably because plant breeders have made resistance to disease an important objective of their breeding programs. Consequently, well-adapted, high-yielding, resistant or tolerant cultivars are being used successfully to cope with most of the major diseases of soybeans in the U.S.

Control of soybean diseases has been less dependent upon the use of chemicals than is the case for any other pest. The reason for this is that prior to 1974, when benomyl was registered for use as a foliage spray, few effective fungicides, except those used for seed treatment, were available for use on soybeans.

Less attention has been given to the development of economic injury thresholds for pathogens than for any other class of pests, primarily because of technical difficulties involved in population assessment of pathogenic organisms. Consequently, chemicals used for seed treatment or foliage application are applied as preventive treatments. This is a serious handicap to the use of fungicides in IPM systems. Research on the problem deserves much more attention than it is receiving. This has become an especially critical need with development of synthetic organic fungicides, some of which have been used widely during the last five years, e.g., benomyl.

The development of effective foliar fungicides for control of several important diseases presents plant pathologists with some interesting options: 1) They can refrain from recommending these chemicals for use on soybeans and continue to rely exclusively on the time-tested methods of rotation, resistant cultivars, destruction of plant debris, and planting pathogen-free seed; 2) they can turn to increased dependence on fungicides for control of the major diseases as effective compounds are available; or 3) they can integrate all of these tactics into IPM systems.

There is convincing evidence that the third option is the most appropriate choice. Problems of resistance to insecticides was a major factor that caused entomologists to

accept the IPM concept more readily than members of other protection disciplines. Unfortunately, it appears that too many plant pathologists may not be ready to profit from the mistakes of the entomologists. Delp (1980) pointed out that resistance to plant disease control agents was not considered to be of sufficient importance to justify a review as recently as 12 years ago. However, 35 genera of pathogens have now developed resistance to agricultural fungicides, many to the point that practical field problems are involved.

One of the most urgent needs for future research on control of pathogens is for development of economic thresholds that can be used to decide whether or not control measures should be initiated. Urgently needed also is research on natural control agents and the impact of pathogenic organisms on soybean pests.

Insects

The numbers of insect pests, like those of the other three classes, have increased dramatically since publication of Piper and Morse's (1923) book. Also, insects show no indication of having filled the available niches in soybean ecosystems. Being more mobile than most members of the other pest classes, the potential for introduction and colonization of exotic species is greater. The annual immigration and colonization of soybeans by migrant species that are major pests, such as *Pseudoplusia includens* and *Anticarsia gemmatalis*, in the Gulf Coast area especially, appears to be unique among soybean pests.

Estimates of losses to soybeans by insect pests have been determined by "educated guesses." Therefore, they are as inaccurate as those available for other classes of pests and may do more harm than good. They range from about 2% (Ennis, 1976) to 30% of total production. Neither extreme appears to be reasonable. It is likely that they would fall somewhere between 5% and 10%. Knowing actual losses is not as important as knowing that several species are capable of inflicting high losses upon soybeans in substantial areas of soybean producing areas every year. Kogan (1979) lists eight species.

Strategies for controlling insect pests of soybeans in the U.S. have mainly evolved from cooperative, coordinated research guided by three projects: Southern Regional Research Project on control of soybean pests; the Huffaker Project on integrated pest management; and its successor, the CIPM Project, often called the Adkisson Project.

Many of the scientists involved with soybean insects had been associated with research on cotton insects, which demonstrated so effectively the hazards of relying exclusively on unilateral use of insecticides. These scientists were anxious to develop systems of control for insect pests that were soundly based on the concepts of IPM.

The following were recognized as being the most important needs (Newsom et al., 1980): Define the pest status of the complex of species known to attack soybeans; develop reliable economic injury thresholds for the species determined to be major pests; develop accurate sampling methods for the various species; discover more selective insecticides and ways of using broad spectrum chemicals in order to quickly reduce substantially, or eliminate entirely, the common practice of applying heavy rates of mixtures of organochlorine and organophosphorus insecticides to soybeans.

Most of these objectives were achieved in a relatively short time. The results of this research effort, supplemented by results of ecological studies on natural control agents, were used to develop provisional IPM systems for control of soybean insects that consisted of the following elements: using economic damage thresholds as the basis for insecticide use decisions; assessing pest populations and their natural enemies at regular intervals during the periods when the crop is at risk; making maximum use of natural control agents; using early-maturing cultivars and selecting planting dates to reduce or avoid populations of some species, particularly *Heliothis zea;* using trap crops of early-maturing Group V cultivars for control of *Cerotoma trifurcata* and *Nezara viridula;* and using minimum rates of the most selective insecticides when economic damage levels are exceeded.

Subsequent research on these projects has been devoted to accumulating the data required to refine and improve the systems developed earlier. Much of the effort has been multi-disciplinary. Sources of resistance to *Epilachna varivestis, Heliothis zea, Pseudoplusia includens, Plathypena scabra, Anticarsia gemmatalis,* and *Nezara viridula* have been identified (Elden et al., 1974; Gilman et al., 1982; Jones and Sullivan, 1978; Kogan, 1975; Schillinger, 1976; Turnipseed and Sullivan, 1976; and Van Duyn et al., 1971). However, commercially acceptable insect resistant cultivars have not been developed. A similar situation exists for entomopathogenic organisms (Ignoffo et al., 1976; Newsom et al., 1980). An additional disappointment was failure to produce a useful computer model of soybean insect pest populations, although substantial

progress has been made toward achieving this objective.

PEST COMPLEXES

Pest complexes and their interactions have received little attention from soybean researchers. Nevertheless, pest complexes are more damaging to soybeans than any single class of pests. Attempts to assess losses to soybeans of any class of pests have been based almost entirely on evaluations of single species, but species do not occur singly. The effects of multiple species attacking a plant, or often a specific part of the plant, at the same time may be additive, synergistic, or antagonistic. Interactions may be more important than main effects.

Growers long have recognized the importance of pest complexes in establishing economic damage levels. They have been quick to point out the inadequacies of economic damage levels determined for a single species by asking the following kinds of questions. "You tell me to treat when populations of insect A reach a certain level, or when population B reaches its economic damage level, or when C reaches its damage level. What do I do when populations of A, B, and C each reach 50% to 75% but none reaches its specific economic damage level? What do I do when species A, B, and C of both nematodes and plant pathogens occur simultaneously with the insects?" The answers to these questions are not available but they must be found.

Cooke (1979), in discussing priorities for British soil science, paid special attention to the question of interactions in fertilizer applications. He stated that both the "law of diminishing returns" (Metscherlich equation) and Liebig's "law of the minimum" work when effects are calculated for fertilizer applications, but that neither works where interactions are involved. Further, he reported that intersecting straight lines give a better fit for response to nitrogen in many crops than fitting data to quadratic equations. He stressed also the importance of what he called mistakes in research on interactions: indiscriminate averaging of inaccurate experiments; testing too few fertilizer rates; paying too much attention to the "law of diminishing returns"; and having an "undue reverence for statistics." These findings have great relevance to the problems of interactions between pest species.

The importance of interactions between biological entities was recognized by Blackman (1905) more than three-quarters of a century ago when he stated, "The way of those who set out to evaluate exactly the effects of changes in a single factor upon a multiconditioned metabolic process is hard, and especially so when the process is being pushed towards the upper limits of its activity." It appears certain that at least some of the major barriers to improved yields of soybean will not be removed until interactions of pest species are better understood. A "crash program" of research on the subject appears to be justified and long overdue.

The problem of improved biological fixation of nitrogen has been assigned a high national research priority in recommendations developed in recent studies (Anonymous, 1978b; Wittwer, 1980; and U.S. Department of Agriculture, 1981). The expected response to such recommendations - increased research in genetic engineering, breeding cultivars that are more efficient in fixing nitrogen, and discovering more efficent strains of *Rhizobium* - illustrates the importance of interactions. The fact that several species of insects, nematodes, and plant pathogens have major direct and indirect effects on nitrogen fixation in soybeans (Baldwin et al., 1979; Lehman et al., 1971; Newsom et al., 1980; Orellana and Worley, 1976; and Orellana et al., 1978) seems to have been overlooked. Data available on the interactions of pests and biological nitrogen fixation suggest that research devoted to this subject will deliver more immediate and larger returns than that devoted to more glamorous areas such as bioengineering. Research on effects of pests on biological nitrogen fixation in soybeans has made a solid beginning. However, little has been accomplished on the relationship of damage by pest complexes to photosynthetic efficiency of soybeans. Literally nothing is known about the effect of pest complexes and their interactions on root growth and development and the supply of water and nutrients to above-ground parts of the plant.

It does not appear likely that development of more efficient plants will revolutionize yields of soybeans until the barriers to increased yields of presently available cultivars are better understood. Undoubtedly plant breeders and genetic engineers can develop improved potentials for yields, but these cannot be fully realized without adequate protection from pests. Adequate protection from pests cannot be provided until the interactions of pest complexes are understood. Research toward establishing a better understanding and effective management of pest interactions, as well as others that occur between inputs to production systems, will contribute more to

significant increases in soybean yields in the near future than any other research effort. When the kinds and amounts of highly cooperative and well-coordinated interdisciplinary research are organized and carried out, it will be possible to have a better understanding of the interactions of pest complexes.

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Major Diseases and Pests of Soybeans in China

HU JI-CHENG, GUO SHOU-GUEI, AND YU ZI-LIN

Soybeans originated in China and have been cultivated there for more than 5,000 years. Wild soybeans can be found throughout the country, and China is rich in soybean germplasm.

Many soybean diseases and pests exist in China. More than 30 diseases occur on soybeans (Table 1). More than 70 insect pests are harmful to soybeans, but only 20 cause serious damage (Table 2).

MAJOR DISEASES OF SOYBEANS

Soybean mosaic virus (SMV), bacterial blight, bacterial pustule, downy mildew, soybean rust, frogeye leafspot, and soybean cyst nematode cause production losses, but these diseases only occur in some production areas. Peanut mottle virus (PMV) and alfalfa mosaic virus (AMV) also infect soybeans. The chief nematode pest is the soybean cyst nematode. Other diseases are minor.

Similarities exist between soybean diseases occurring in southern China, where soybeans are sown in summer and autumn, and in northern China, where soybeans are sown only in the spring. Owing to different climatic conditions, the degree of incidence varies. For example, soybean rust, anthracnose, and bacterial pustule are serious diseases of soybeans in southern China, while downy mildew, frogeye leafspot, bacterial blight, and soybean cyst nematode cause serious damage in northern China. Soybean mosaic virus causes some damage in all soybean producing areas, while PMV and AMV occur in limited areas.

MAJOR INSECT PESTS OF SOYBEANS

The soybean aphid is one of the major insect pests of soybeans. This pest can be found in all soybean producing areas in China and seriously affects yield. Pod and seed pests include the soybean pod borer in the northeast and the North China Plain, sometimes damaging 40% of the seeds, and the limabean pod borer in southern China. Seedlings are attacked by the smaller velvety chafer, two-striped leaf beetle, and the Mongolian gray weevil, which cause serious damage in the spring-sown area. The seedlings can sometimes be killed. The root miner fly is spreading in the northeast and North China Plain. The soybean fly, which causes serious damage in Shandong, Henan, Anhui, and Jiangsu provinces, attacks mature plants. Pests harmful to the leaves include bean blister beetle and Chinese blister beetle. These two pests are widely distributed. The greenish yellow-brown hawk moth can be found in Shandong, Henan, Anhui, and Jiangsu provinces, and the flax bud worm in the northeast, the North China Plain, and the Inner Mongolia Autonomous Region. Larvae of the bean tussock moth, three-spotted phytometra, common cutworm, yellow-belly black-dotted arctiid, white tiger moth, and soybean woolly bear are all defoliators but are serious pests only in some areas.

PARASITIC WEEDS

Cuscuta chinensis is a parasitic weed on soybeans and other plants. It is found throughout China's vast soybean production areas. In southern China, both *Cuscuta australis* and *C. chinensis* cause serious damage. At harvest, seeds of this weed are mixed with soybean seeds, and the infestation expands during the next season. Yield reduction is often 5-10%, but occasionally exceeds 40%.

THE CONTROL OF SOYBEAN DISEASES AND INSECT PESTS

Prevention is the major approach to the control of soybean diseases and insect pests in China. Sound agricultural management is integrated with plant resistance and chemical control.

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Table 1. Major diseases of soybeans in China

	Common name	Pathogen
Leaf diseases	Downy mildew	*Peronospora manshurica*
	Frogeye leafspot	*Cercospora sojina*
	Brown spot	*Septoria glycines*
	Phyllosticta leafspot	*Phyllosticta sojaecola*
	Alternaria leafspot	*Alternaria brassicae* var. *phaseoli* *A. fasciculata* *A. tenuis*
	Soybean rust	*Phakopsora pachyrhizi*
	Target spot	*Corynespora cassiicola*
	Powdery mildew	*Erysiphe polygoni*
	Soybean sleeping blight	*Septogloeum sojae*
	Bacterial blight	*Pseudomonas syringae* f. sp. *glycinea*
	Bacterial pustule	*Xanthomonas campestris* pv. *phaseoli*
	Soybean mosaic virus	Soybean mosaic virus
	Mycosphaerella leafspot	*Mycosphaerella sojae*
	Sunburn injury	Nonparasitic
Stem diseases	Sclerotinia stem rot	*Sclerotinia sclerotiorum*
	Stem blight	*Phomopsis sojae* (*Diaporthe phaseolorum* var. *sojae*)
	Pellicularia blight	*Pellicularia sasakii*
Root diseases	Rhizoctonia root rot	*Rhizoctonia solani*
	Pythium rot	*Pythium debaryanum*
	Fusarium wilt	*Fusarium bulbigenum*, *F. oxysporum*
	Soybean cyst nematode	*Heterodera glycines*
Seed and pod diseases	Purple seed stain	*Cercospora kikuchii*
	Ascochyta spot	*Ascochyta glycines*
	Scab	*Fusarium avenaceum* *F. roseum* *F. semitectum*
	Pod blight	*Macrophoma mame*
	Anthracnose	*Colletotrichum truncatum* var. *truncatum*
	Sphaceloma scab	*Sphaceloma glycines*

Agricultural Management

Resistant cultivars. Cultivars resistantto diseases and pests are used. At present, most cultivars are resistant to several major diseases. There are numerous soybean diseases in China, but with resistant cultivars seldom occur in large areas or cause serious yield reduction. The main approach to control of soybean pod borer is the use of resistant cultivars.

Rotation and cultivation. Rotation and deep plowing are effective ways to eliminate disease-infected stalks and leaves, thus minimizing the sites for bacteria and pests to overwinter. Meticulous farming, draining water from the water-logged fields, and applying additional farm-yard manure, phosphate, and potash fertilizer also help to control outbreaks of diseases and improve the resistance of plant crops. Rotation can help control nematodes.

Table 2. Major insect pests of soybeans in China

Soybean growth stage	Common name	Scientific name
Seedling	Root miner fly	*Ophiomyia shibatsuji* (Diptera:Agromyzidae)
	Bark feeding cutworm	*Agrotis segetum* (Lepidoptera:Noctuidae)
	Larger cabbage cutworm	*Agrotis tokionis* (Lepidoptera:Noctuidae)
	Black cutworm	*Agrotis ypsilon* (Lepidoptera:Noctuidae)
	Spotted cutworm	*Agrotis c-nigrum* (Lepidoptera:Noctuidae)
	Oriental garden cricket	*Gryllus testaceus* (Orthoptera:Gryllidae)
	Mongolian gray weevil	*Xylinophorus mongolicus* (Coleoptera:Curculionidae)
	False wire worm	*Opatrum subaratum* (Coleoptera:Tenebrionidae)
	Smaller velvety chafer	*Maladera orientalis* (Coleoptera:Scarabaeidae)
	Onion thrips	*Thrips tabaci* (Thysanoptera:Thripidae)
	Two-striped leaf beetle	*Monolepta negrobilineata* (Coleoptera:Chrysomelidae)
Vegetative stage	Soybean aphid	*Aphis glycines* (Homoptera:Aphidae)
	Cotton red spider	*Tetranychus urticae* (Acari:Tetranychidae)
	Small bean bug	*Chauliops fallax* (Hemiptera:Lygaecidae)
	Bean globular stink bug	*Coptosoma cribraria punctatissima* (Hemiptera:Plataspididae)
	Greenish yellow-brown hawk moth	*Clanis bilineata* (Lepidoptera:Sphingidae)

Seed selection. Select seeds carefully and discard infected seeds.

Chemical Control

Pesticides can control outbreaks of various pests and preserve germplasm. BCM (Carbendazim) (50%) diluted 500 times in a suitable solvent is used to control frogeye leafspot and downy mildew, and Bayletan is used to control soybean rust. D-D or Furadan is used in the control of soybean cyst nematode. At the time of sowing, 0.3-0.5% thiram (TMTD) is mixed with the seeds to reduce seed-borne pathogens. None of the cultivars currently used are resistant to the soybean aphid. When an outbreak is serious, 1.5% dimethoate (Rogor) powder or 4% Rogor emulsifying oil in 1,500-2,000 times solution is recommended. For control of the soybean pod borer, 80% DDVP is used to kill the adults by fumigation or 2% Baytex powder is broadcast to kill the adults and larvae. For the control of the larvae of flax bud worm, bean tussock moth, and the yellow-belly black-dotted arctiid, 2.5% Dipterex powder or 90% Dipterex with 1,000 times solution is used. To control pests in the seedling stage, Lindane powder is mixed with seeds at the time of sowing, or poisoned millet is used which will control smaller velvety chafer, root miner fly, two-striped leaf beetle, etc.

Biological Control

More than 10 natural enemies of soybean Lubao No. 1 can be used to control *Cuscuta chinensis*. Fungous preparations of *Beauveria bassiana* and parasitic wasps, *Trichogramma* sp., have achieved promising results in controlling the limabean pod borer.

Table 2. Major insect pests of soybeans in China (continued)

Soybean growth stage	Common name	Scientific name
Vegetative stage	Three-spotted phytometra	*Phytometra agneta* (Lepidoptera:Noctuidae)
	Cotton geometrid	*Ascotis selenaria dianeria* (Lepidoptera:Geometridae)
	Flax bud worm	*Heliothis dispacea* (Lepidoptera:Noctuidae)
	Bean tussock moth	*Cifuna locuples* (Lepidoptera:Lymontriidae)
	Meadow moth	*Loxostege sticticalis* (Lepidoptera:Pyralidae)
	Yellow-belly black-dotted arctiid	*Spilarctia lubricipeda* (Lepidoptera:Arctiidae)
	White tiger moth	*Spilarctia subarnea* (Lepidoptera:Arctiidae)
	Soybean woolly bear	*Amsacta lactinea* (Lepidoptera:Arctiidae)
	Bean pyralid	*Lamprosema indicata* (Lepidoptera:Pyralidae)
	Bean leaf folder	*Matsumuraeses phaseoli* (Lepidoptera:Tortricidae)
	Chinese blister beetle	*Epicauta chinensis* (Coleoptera:Meloidae)
	Bean blister beetle	*Epicauta gorhami* (Coleoptera:Meloidae)
	Soybean fly	*Melanagromyza sojae* (Diptera:Agromyzidae)
	French bean fly	*Agromyza phaseoli* (Diptera:Agromyzidae)
	Leguminous pod borer	*Maruca testulalis* (Lepidoptera:Pyralidae)
Reproductive stage	Soybean pod borer	*Leguminivora glycinivorella* (Lepidoptera:Tortricidae)
	Limabean pod borer	*Etiella zinckenella* (Lepidoptera:Pyralidae)

These natural enemies will be released into production areas after thorough investigation and research.

In the future, the main objectives of research work in soybean disease and pest control will involve the breeding of multiple resistant cultivars and improvement of existing control measures. Attention should be focused on biological control and minimizing the use of chemicals to reduce environmental pollution. We need to study outbreak patterns of major diseases and pests so that our national forecasting network can be expanded.

Processing and Utilization Activities of Soybeans in the United States

ENDRE F. SIPOS, JOSEPH G. ENDRES, AND LEAMON D. WILLIAMS

Although soybeans go back to ancient times in the Orient, their history in the U.S. covers a very recent period. Soybeans in the U.S. were used as hay and silage for a number of years before the value of their oil and protein for food and feed was recognized; commercial processing of the seed was not established until 1922 (Horan, 1974). Demand for seed gradually increased with improved methods of cultivation, the development of markets for the oil, and the technical advances and nutritional knowledge of how to process and feed soybean meal to monogastric animals.

METHODS OF PROCESSING

Historical Perspective

A. E. Staley, a corn processor located in Decatur, Illinois, visualized the advantages to the midwestern U.S. of a domestic supply of oil and meal and became a missionary among Illinois farmers on growing more soybeans. In 1921, he announced that his company would open a soybean processing plant by harvest time in 1922. Following this, other oil mill processing plants were built. By the mid-1930's, the soybean processing industry in the U.S. was firmly established, and markets for soybean oil and meal were well developed. In 1948, the processing capacity in the U.S. was over 5,443,000 metric tons, and in 1951, 8,437,000 metric tons. This compares with 28,304,700 metric tons processed in 1980 (Horan, 1974; Markley, 1950).

The continuous screw-press process was the chief means of processing beans prior to World War II. It was replaced by solvent extraction, and in the late 1940's, about half of the U.S. soybean crop was handled by the solvent extraction process. By 1982, over 99% of the total crop was solvent extracted.

The first large-scale continuous solvent extraction plants were introduced from Germany in 1934. Both the Hildebrandt "U"-type and the Hansa-Muhle or Bollman basket-type extractor were used exclusively until 1937, when the vertical gravity extraction columns were introduced. Modifications and improvements in extraction units have increased efficiency, dependability, simplicity, and safety (Horan, 1974; Markley, 1950). Considerable research was devoted to finding the most efficient and practical solvent for extraction. Because of its nonflammability, trichloroethylene was promising at one time. After toxic symptoms were observed in cattle fed trichloroethylene-extracted meal, it lost popularity. Commercial hexane has filled the requirements better than any other solvent because of its low cost, easy recovery, and selectivity for vegetable oils.

One of the milestones in soybean meal utilization was the discovery and elimination of heat-liable antinutritional factors (Markley, 1950). Prior to 1951, the most popular desolventizing-toasting equipment was the horizontal-type, steam-jacketed paddle conveyor (Schneckens). A method described by Kruse gained acceptance in 1951 because it combined desolventizing and toasting in a single vessel and produced a meal of superior quality. This type of toasting is applicable where solvent-saturated flakes are introduced directly to a cooker and live steam is added within the cooker. The nutritive value of the meal is enhanced greatly in this process by the efficient destruction of anti-trypsin activity, yet essential nutrients remain preserved (Cravens and Sipos, 1958).

The soybean industry in the U.S. is different from other oilseed industries in the number of plants processing at very high capacities. The early solvent plants ranged in size from 45 to 90 metric tons daily

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capacity. However, in the early 1960's, as soybean production increased and mechanization of the plants improved, the size of the plants that exclusively process soybeans increased to a range of 900 to 2,720 metric tons daily capacity.

The industry that produces edible soy protein has grown enormously, and its products are past the point of trial and into an era of large volume use and continuing growth. Since the late 1960's, the annual consumption of edible soy protein in the U.S. has grown to approximately half a billion kilograms - an amount equal to approximately 2 kg per person. However, this is still an insignificant amount in comparison to the total tonnage of soybean meal manufactured in the U.S. (Soy Protein, 1978).

An enormous amount of research and improvements in manufacturing techniques have made possible the use of soybean oil for human food and other industrial products. By the 1930's, the industrial uses of soybean oil started to decline because of competition from synthetic resins and detergents. Research by both government and industrial laboratories on the chemistry of oil flavor reversion resulted in improved processing. Consequently, oil flavor reversion was greatly reduced, making soybean oil more acceptable in shortenings, margarines, and cooking oils. Because of these quality improvements and the abundance of low-cost soybean oil, it became the most important food fat in the U.S. Nonfood uses have declined to less than 2.5%. In 1979-80, domestic consumption averaged nearly 3.9 billion kg per year, which was larger than the production or disappearance from the market of any other vegetable oil in the U.S. for that period, and was equal to about 67% of total domestic disappearance from the market of all fats and oils (Soya Bluebook, 1981).

Description and Manufacture

When soybeans enter the processing plant, they are screened to remove broken or damaged beans and foreign materials (Fig. 1); then flow into double cracking rolls where the beans are cracked to allow the hulls to break away. The hulls are removed by air in the dehullers. Hulls are heat-processed (85°-105°C), milled, and sold for feed purposes. The cracked cotyledons, often called bean chips or meat, are heat-treated in a conditioner (60°-65°C) to make them plastic for flaking. This is performed on huge rolls set to produce flakes of uniform thickness (0.25-0.4 mm). The oil is removed from the flakes by commercial hexane in one of several types of countercurrent systems discussed previously. The oil-rich hexane miscella then is heated (100°-115°C) and stripped with live steam to drive off the hexane. The oil is degummed by steam or hot water hydration, centrifuged, and dried. The gums obtained are dried and sold as natural grade lecithin, or processed further into one of many types designed for specific applications. After the defatted flakes leave the extractor, the hexane is drained off, and residual hexane removed by heat or vacuum.

The three basic soy protein products derived from defatted flakes are soybean meal and flour, soy protein concentrates, and soy protein isolates (Table 1). For meal production, the flakes are treated in a desolventizer-toaster. The toasted product is ground to size and sold as soybean meal (44-49% protein). Soybean meal and flour (40-50% protein) are obtained by removing fat from soybean flakes. The degree of fat removal and the heat treatment used in processing differentiate the commercially available products (Horan, 1974) (Fig. 2).

Soy protein concentrates are obtained by removing oligosaccharide material from defatted flakes or flour. Several different commercial processes are used. All arrive at a 70% protein product, on a moisture-free basis, as required by definition (Horan, 1974; Meyer, 1970). Soy protein isolates are obtained by extracting defatted flakes with water or mild alkaline solutions and contain 90% protein on a moisture-free basis, as required by definition (Horan, 1974; Meyer, 1970).

Textured soy protein may be produced by spinning technology (Alden, 1975; Gutcho, 1973), thermoplastic extrusion (Smith, 1976), and steam texturization (Valentas and van Hulle, 1974). Thermoplastic extrusion and steam texturization of soy flour and soy protein concentrate are the most widely used commercial techniques.

A simplified diagram of the unit processing steps for refining, bleaching, and deodorizing soybean oil is shown in Figure 3. Crude oil is continuously alkali-refined 24 hours a day, 7 days a week, using modern processing equipment with computer-controlled systems. In the alkali-refining step, impurities which influence finished oil quality and stability are removed, such as free fatty acids, color bodies, metallic pro-oxidants, and residual phosphatides.

Bleaching with activated clay further removes pigments, residual soaps, and moisture. Hydrogenation reduces unsaturation, particularly linolenic acid, and improves oil stability. After hydrogenation, the oils again are bleached with activated clay to remove residual trace metals such as

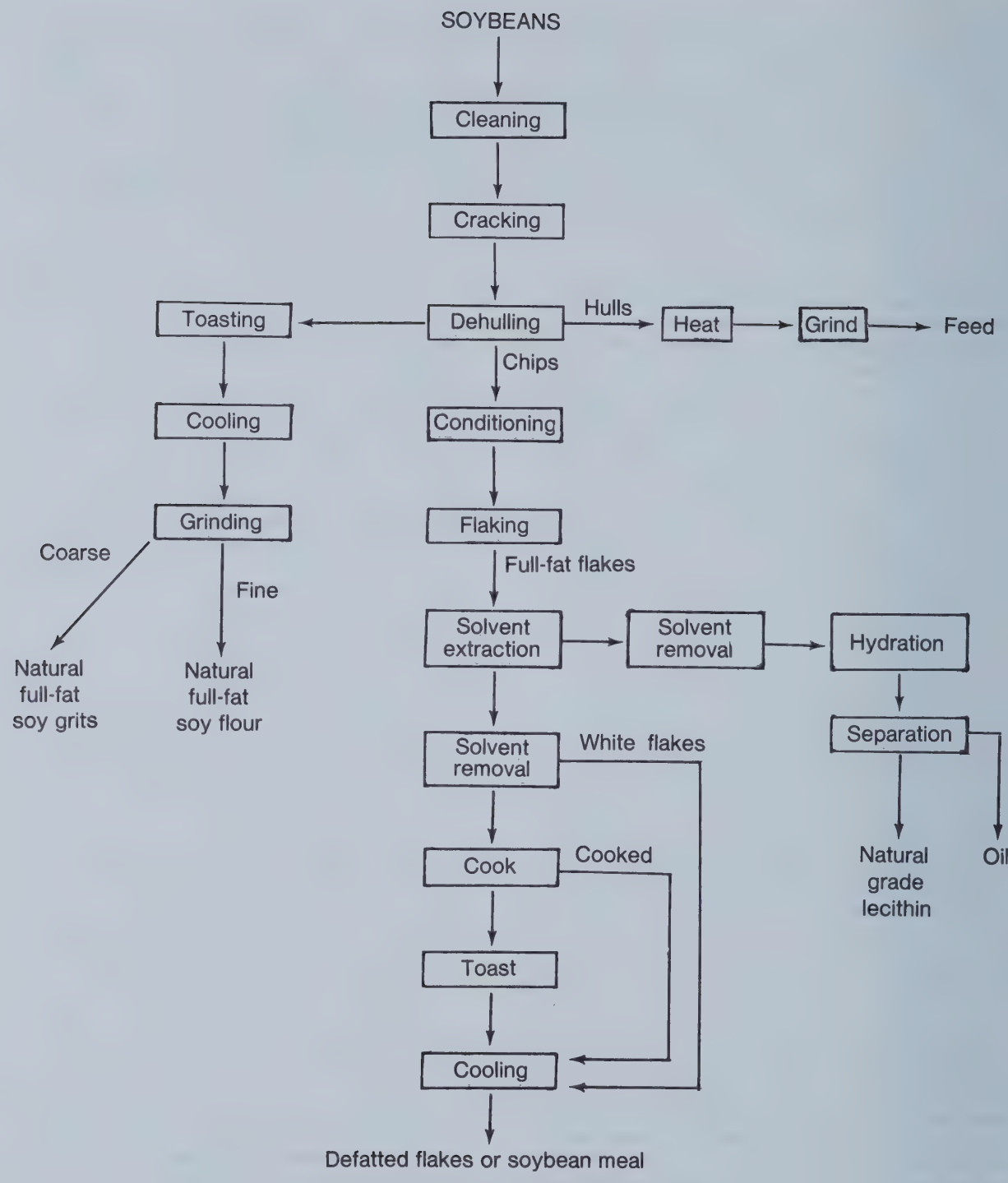

Figure 1. Soybean processing.

nickel. Deodorization is a very important step at this stage of the process, because undesirable flavor components are removed. Deodorization is a high-vacuum, high-temperature (230°-265°C) steam distillation process. After deodorization, the oil is protected by nitrogen blanketing in closed system storage tanks. Modern oil processing plants require the support of skilled analytical people and state-of-the-art equipment to develop the objective measurements needed for quality control.

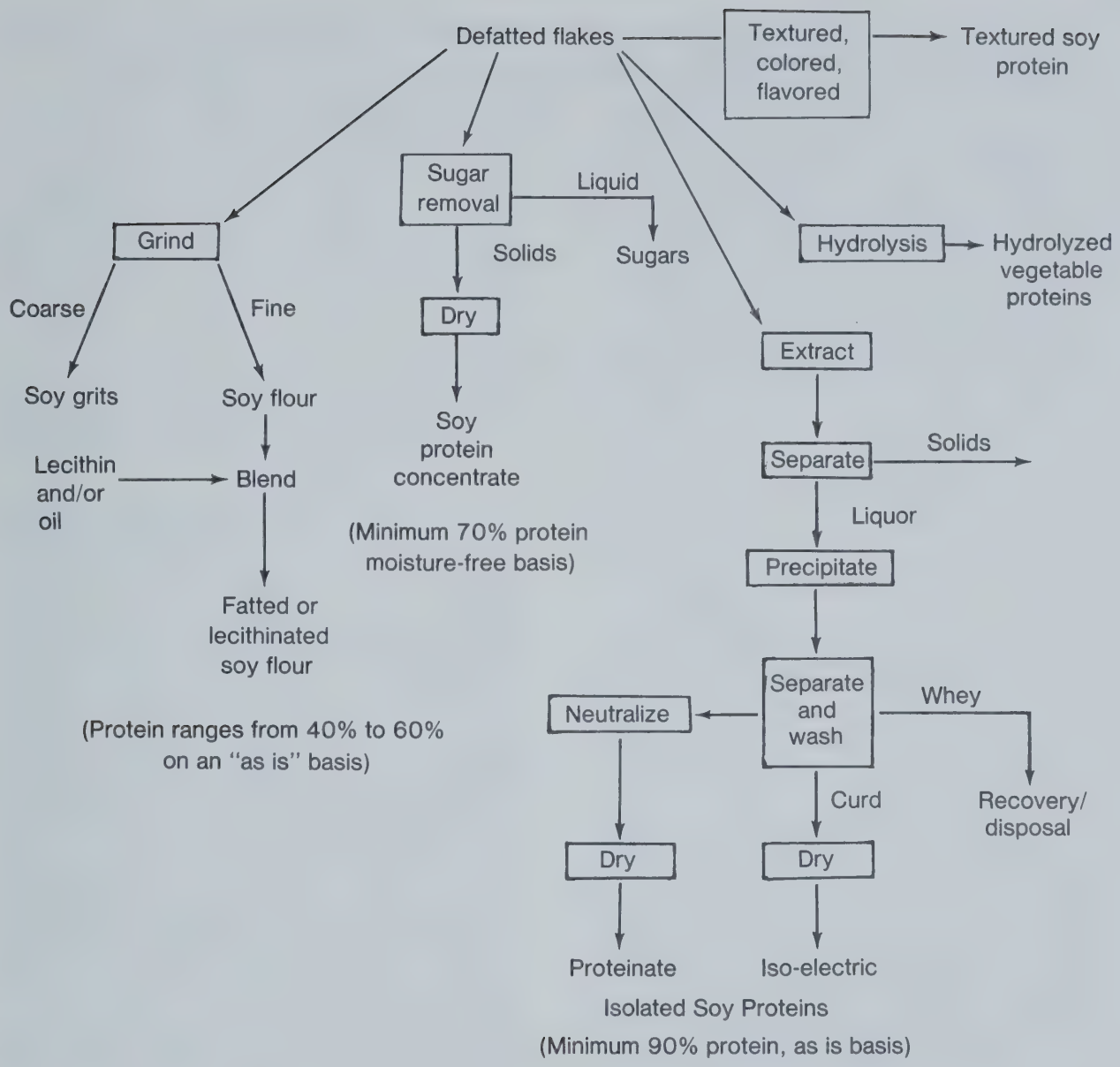

Figure 2. Soy protein products from defatted flakes.

UTILIZATION

Soybean Meal for Feed

Soybean meal for livestock feed is the major soybean product manufactured in the U.S., with an estimated use in 1980-81 of 91% of all oilseed meals (Soya Bluebook, 1981). During the early years of soybean production, the meal, or cake as it was called, generally was regarded as a byproduct of little value; it was used as cattle feed or occasionally as a fertilizer. The use of soybean protein for poultry, swine, and other animal feeds was not developed until the late 1930's (Cravens and Sipos, 1958).

A review of the literature reveals that many of the milestones of nutrition were reached in the course of experiments wherein soybean meal replaced varying quantities of ingredients of animal origin in livestock and poultry rations. Studies on the need for and requirements of minerals and vitamins by animals and poultry were intensified through difficulties that arose when soybean meal replaced ingredients of animal origin. Hayward et al. (1936) studied the effects of

Table 1. Proximate analyses of commercial soy protein products

Product[a]	Moisture (%)	Protein (N x 6.25) (%)	Fat (%)	Crude fiber (%)	Ash (%)
Soy flour and grits, full fat	5.0	44.3	22.1	2.1	5.2
Soy flour and grits, defatted	7.0	54.9	0.9	2.6	6.4
Soy flour, lecithinated	5.5	45.9	16.4	2.2	5.3
Soy protein concentrate	7.5	66.6	---	3.5	5.5
Isolated soy protein	5.0	93.1	---	0.2	4.0
High-protein soybean meal	12.5	49.5	1.0	3.2	5.6
44% protein soybean meal	12.2	45.1	1.0	6.7	5.6

[a]Defatted soy flour and grits are available in a variety of heat treatments.

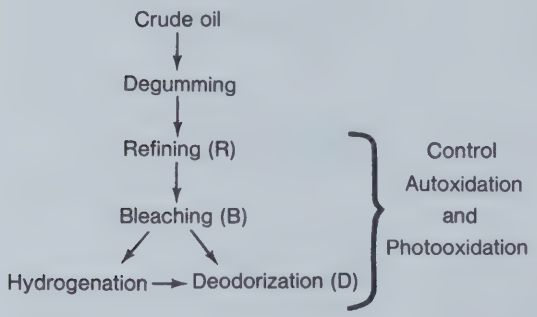

Figure 3. Unit processing steps for RBD soybean oil.

heat and moisture on the nutritive value of the protein during processing. They demonstrated that moist heat treatment is necessary for developing the optimum nutritional value of the protein and that the limiting amino acid in soybean protein is methionine. It became increasingly evident, however, that vitamin and mineral factors were as involved as protein for the quality of rations when soybean meal is the prime source of protein.

As a result of numerous later studies, soybean meal has attained a prominent place in poultry feeding. A typical broiler feed may contain 17-22% protein, of which more than 90% usually comes from soybean meal (Cravens and Sipos, 1958) (Table 2). Poultry nutrition, rations, breeding, housing, anatomy, physiology, metabolism, disease control, and economics all played a part in the development of this industry. The most important factor responsible for increasing the feed efficiency in poultry production was the utilization of a high-protein diet containing the dehulled and defatted soybean meal. The efficiency in broiler production increased from a gain of about 4 kg of feed per kg of bird in 1948, to the present rate of 2 kg of feed per kg of bird. Poultry and

Table 2. Composition of typical commercial broiler feeds

	Starter (%)	Grower (%)	Finisher (%)
Maize	59.00	62.30	66.00
Soybean meal	35.00	30.50	27.90
Fat	3.10	4.50	3.70
Phosphate	1.65	1.50	1.20
Limestone	0.50	0.50	0.50
Salt	0.25	0.25	0.30
Methionine	0.18	0.15	0.12
Choline	0.07	0.05	0.03
Vitamin/trace mineral/drug premix	0.25	0.25	0.25

egg production, formerly the part-time occupation of the farm wife, has been relocated to large-scale poultry houses which depend mostly on the mixed feed industry for a scientifically formulated feed supply. The U.S. mixed feed industry produces more than 29 million metric tons of poultry feeds annually and generally is reported to consume more than 50% of the soybean meal processed in the U.S.

Experimental work on feeding soybean meal to swine closely paralleled that outlined with poultry. When soybean meal replaces animal products in swine rations, calcium and phosphorus are the critical minerals, along with the need for proper heat treatment for maximal nutritive value (Cravens and Sipos, 1958) (Table 3). As a result of the abundant supply of high-quality soybean protein, as well as improved housing and management, feed efficiencies of about 3.5 (birth to market) are being achieved. Very efficient commercial swine operations are achieving feed conversion ratios of 2.9.

Soybean meal also is an excellent protein supplement for fattening beef cattle

Table 3. Composition of typical commercial swine feeds

	Starter (%)	Grower (%)	Finisher (%)
Vitamin and mineral premix	5.00	3.00	3.00
44% protein soybean meal	27.50	21.25	15.75
Maize	67.50	75.75	81.25

and for the breeding herd. Its usefulness in calf starter rations and in feeding dairy cows also has been demonstrated (Ellis, 1958).

Edible Soy Protein Products

Earlier, it was the hope of many leaders of agriculture, government, and industry that much of the oil and protein of the soybean could be diverted from the food and feed industries into industrial products such as paints, varnishes, soap stock, plastics, adhesives, plywood glue, paper coating and lamination, paper sizing, textile fibers, and other uses. In 1935, the Glidden Company built the first plant for the isolation of industrial-grade soybean protein (transferred to Central Soya in 1958) (Horan, 1974; Markely, 1950). While the soybean proteins have several important industrial applications, the original dream of an ever-expanding industrial market has faded. It is recognized generally that the increasing demands for protein for feed and food will greatly surpass industrial uses.

Because soybeans are not a traditional food staple, the most popular and important sources of food protein in the U.S. continue to be meat, poultry, eggs, dairy, and fish. The steadily increasing cost of these proteins has prompted the food industry to focus on vegetable sources of protein, principally the oilseeds. Following the war period and with initiation of research on soy foods, a better understanding of the functional uses of soy flour in bakery products was developed. In about 1960, several soybean protein concentrates (70% protein/dry basis) appeared on the market, and these are used as meat extenders, in bakery products, and in several other food applications. In addition, concentrates produced by the aqueous-alchohol process are used widely in calf milk replacers and baby pig starter feeds. Several types of edible isolate soybean protein (90%) appeared in the U.S. in commercial quantities in the early 1960's. Also available are modified and hydrolyzed soy protein products.

Textured protein products (TPP) have become commercially important in the U.S. These products can be manufactured by spinning soy protein isolate into a "tow" of fibers and shaping and flavoring into desired food-like products; by processing formulated soy flour or concentrate through an extruder into different sizes and shapes; and to form a chewy gel by heat treatment of a soy protein isolate dispersion (Horan and Wolff, 1974).

The trend toward quick-service convenience foods requiring fabrication, dehydration, and rehydration brought the versatility of the textured soy proteins to the forefront in the mid- and late-1960's. Likewise, the economic performance of soy protein in chopped emulsified meats, egg white replacement in cakes, and the substitution for non-fat dry milk in baked goods all point to a lower cost per unit of performance while maintaining the required level of consumer acceptance (Hooton and Johnson, 1978).

We are now in the era in which nutrition must play a more decisive part for three reasons: increasing awareness of protein nutrition by consumers who consider it an important factor to the improvement of their well-being; the positive action the government agencies have taken to set minimum standards for certain foods, as well as what officially constitutes "lunch" and "dinner"; and the effect of progressive shortages of protein on a world scale.

The wealth of food product applications developed with soy protein is proof of their success and the satisfaction with this new favorite among food ingredients. Products in every category of commercially or institutionally prepared foods can be formulated to include the use of valuable soy protein (Soy Protein, 1978) (Table 4).

Soybean Oil

Soybean oil occupies first place in the shortening and margarine industry. Beginning early in the 1950's, soybean oil has taken an increasingly larger share of the margarine market. In 1980, the consumption of bean oil in margarine amounted to about 749 million kg. Soybean oil is used widely in other edible products such as cooking and salad oils, mayonnaise, and salad dressings. Fatty acids, sterols, and tocopherols are important byproducts of soybean oil (Smith and Minor, 1974).

Lecithin

The product obtained by the degumming of crude soybean oil is called lecithin. Soybean lecithin is used widely in the margarine, chocolate, confectionery, ice cream,

Table 4. Important food uses of soybean protein products

Product	Soy protein isolate	Soy protein concentrate	Soy flour (grits)	Textured soy protein
Comminuted meat products				
Frankfurters	X	X		
Bologna	X	X		
Miscellaneous sausage	X	X		
Luncheon loaves	X	X		
Canned luncheon loaves	X	X		
Poultry products	X	X		
Coursely ground meat products				
Patties		X	X	X
Chili con carne		X	X	X
Sloppy joes		X	X	X
Meat balls		X	X	X
Pizza toppings		X	X	X
Bakery products				
Cakes		X	X	
Cake mixes		X	X	
White bread			X	
Specialty breads		X	X	
Cookies, biscuits, crackers, etc.		X	X	
Pancakes			X	
Donuts			X	
Sweet goods			X	
Dairy-type products				
Coffee whiteners	X			
Whipped toppings	X			
Frozen desert	X			
Beverage powder	X			
Cheeses	X			
Dried meat bits				X
Infant formulations	X		X	
Dried soup mixes	X			
Special dietary items	X	X	X	
Breakfast cereal		X	X	

macaroni, and baking industries. Its usefulness in pharmaceuticals, cosmetics, paints, rubber, petroleum products, and the leather and textile fields is worth mentioning.

CONCLUSION

In the U.S. domestic market, soy protein products are gaining acceptance as useful and economic ingredients in the manufacture of mixed animal feeds and conventional foods, as well as the design of new foods. More food package labels are showing soy products in their ingredient listings. We can expect this trend to continue with increasing food product development effort. The soybean industry has been an important part of a high-technology food system by offering excellent nutrition in the production of milk, meat, and eggs, as well as its expanding role as an ingredient in processed foods. With increased world production of soybeans, it is anticipated that the so-called "golden bean" will play an even

greater role in helping to meet world food needs of the future.

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Research on Heat Denaturation of Soy Protein after Solvent Extraction, and Traditional Chinese Soy Foods

GUO XIANG-AO

The production of special protein products from soybeans for human consumption has greatly increased in recent years, and products such as defatted soy flour, soy concentrates, soy isolates, and textured protein are produced in many countries.

Soy protein is one of the most widely known vegetable proteins. It is highly nutritious and can improve the quality of processed foods. Soy protein is cheaper than animal protein, and it is beneficial to human health.

Soybeans must be defatted by solvent extraction and the residual oil in the meal should be as low as possible (1% or below) before soy protein products can be made. We investigated the changes to soy proteins and soy products by the extraction process.

In one experiment we started with soy flakes defatted by solvent extraction. These were heated to 80°C, 90°C, and 100-105°C for either 15 or 20 minutes. Results of the analyses are given in Table 1.

We concluded that under the same temperature conditions, protein denaturation of soy flakes and solvent-extracted meal is influenced by heat exposure; and when the temperature exceeds 80°C, solvent-extracted defatted meal denatured more rapidly than soy flakes.

The critical temperature for heating solvent-extracted meal is 80°C. Defatted meal used for protein products for human food must be treated below this temperature. Processors using a solvent with a wide boiling range may need to change equipment and operating procedures. The boiling point of petroleum ether, for example, is 60° to 85°C.

Soybeans are one of the oldest grain legumes in China, and we have been preparing food from them for more than 1,000 years. China produces more than 9,070,000 metric tons of soybeans per year, and production will increase in the future. Soyfoods are nutritious and inexpensive, and are favored by the Chinese people. Some of the traditional soybean products prepared and eaten in China are: whole soybeans, soy sprouts, soybean jiang, soy nuggets, soy sauce, defatted soybean cake, soybean meal, soy beverage, regular, soft, and firm tofu, pressed tofu sheets, vegetarian chicken, fried tofu, fermented tofu, and yuba. Methods of preparation of these are given in the rest of this paper.

Soy sprouts (dou ya). Soak good quality soybean seeds in water, changing the water two or three times. After the beans have expanded, pour off the water. Place a straw mat in the bottom of a wooden vessel and spread them to give a 3-inch layer of beans. Cover with a straw mat, and seal the vessel to maintain the temperature and moisture. Spray water on the mat three or four times a day. After 10 to 14 days, the soy sprouts are ready.

Soybean jiang (dou jiang). Steam the soybeans thoroughly, add wheat flour (100:55) and the mold *Aspergillus* spp.; place the mixture in a shady and well-ventilated place. After this mixture has fermented for 24 hours, add a 30% salt solution (about 15°Be'), stir, and place in a large container. After 25 to 28 days, at 40-45°C, soybean jiang is produced.

Soy nuggets (dou chi). Soak soybeans for two hours in cold water. Drain and then steam the beans for four hours. Spread the beans on a mat, inoculate with *Aspergillus* spp., and place them in a shady place. After a fermentation period of 15 to 21 days, add 18% salt, 1% distilled alcohol, 16% pure water, and stir. Place the beans in a water-sealed earthenware vessel for six months.

Soy sauce (jiang you). Soy sauce can be made from whole soybeans, defatted soybean cake, or soybean meal. In our experience, soybean cake or soy meal is preferred. Crush the soybean cake or meal, add wheat bran (70:30), water, and stir. Steam heat the mash to 120°C, then cool to 40°C by aeration. Add *Aspergillus* spp. and allow the mash to ferment for 28 hours in a fermentation room (25-30°C). After that, put it into

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Table 1. The effect of temperature for two exposure times on soybean flakes and solvent-extracted meal

Items	Soybean flakes					Solvent-extracted meals					
	80°C	90°C		100-105°C		80°C		90°C		100-105°C	
	20 min	15 min	20 min	15 min	20 min	15 min	20 min	15 min	20 min	15 min	20 min
Moisture content of soybeans, %	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6
Total protein content, %	44.1	42.4	43.8	43.2	43.2	51.4	50.6	50.8	52.8	53.6	53.5
Water soluble protein, %	34.3	34.0	34.0	34.0	33.8	41.8	39.6	38.0	36.3	35.1	33.5
Ratio of water soluble protein to total protein, %	77.7	80.3	77.8	80.3	78.3	80.5	78.3	74.9	69.4	67.6	65.6
Ratio of water soluble protein to raw soybean water soluble protein, %[a]	96.2	99.3	96.2	99.4	96.9	99.6	96.9	92.6	85.9	83.6	81.1

[a]Water soluble protein in raw soybean total protein is 80.85%.

a second fermentation room (40-45°C) and add salt. After 16 to 17 days, fill with a salt water solution (16-19%) and heat to 80°C. After filtering and sterilizing, soy sauce is obtained.

Soy beverage (dou jiang). Clean the soybeans, crush, dehull, soak, grind with water, filter, and boil. The soy beverage now is ready.

Flash-desolventized soybean meal also can be used to produce soy beverage.

Regular and soft tofu (doufu). Tofu (bean curd) is a popular food in China. A coagulant such as calcium sulfate is added to boiled soy beverage that has been cooled to 75-85°C. This will coagulate and gel. After packing and pressing, soft or regular tofu is produced.

Firm tofu (doufu gan). When more coagulant is added to the soy beverage and the packing pressure is increased, a firmer tofu is obtained. This is cut into pieces and boiled in an alkali lye solution for ten minutes, then removed, cooled, and boiled in a caramel solution. When cool, the tofu is brown.

Pressed tofu sheets (doufu yi). Break some tofu into small pieces, spread these on a long piece of cloth, and press to remove excess water. Then remove the cloth and use.

Vegetarian chicken (su ji). Spread a thin layer of sodium carbonate powder on a pressed tofu sheet, roll it up, and seal the roll. These rolls are soaked and boiled in flavored liquids to increase firmness and impart certain special flavors. They are delicious and are called vegetarian chicken.

Fried tofu (you-doufu). Boiled soy beverage is coagulated with calcium choride, thus forming tofu. Water is removed by pressing. The tofu is cut into pieces, and set out to dry for one or two days. When fried in the vegetable oil, fried tofu is obtained. Calcium chloride is used for preparing fried tofu because it swells while frying.

Fermented tofu (doufu-lu). A coagulant is added to soy beverage. Calcium sulfate or calcium chloride is inappropriate for making fermented tofu. The coagulant used for fermented tofu is derived from the whey which was pressed from tofu. The whey sets for two days until the pH reaches 4. The tofu

is wrapped, pressed, cut, fermented, salted, and packed in an earthenware vessel for six months.

Yuba (doufu pi). Soy beverage is poured into a shallow pan and heated slowly. A protein film forms on the surface. This film is rolled and dried until it resembles bamboo. The taste and composition are similar to textured soy protein. It is a very nourishing food.

All these soy foods are favorite traditional foods in China. Today some of these products are made from flash-desolventized soybean meal instead of whole soybeans. We believe that Americans will like soy concentrates, soy isolates, texturized protein products, and also our traditional soyfoods.

Germplasm, Breeding, and Genetics Working Group Session

Convener: Robert M. Goodman

Reporter: Randall L. Nelson

Germplasm Collection, Management, and Evaluation: The Subgenus *Glycine*

THEODORE HYMOWITZ

The genus *Glycine* Willd. is composed of two subgenera, *Glycine* and *Soja* (Moench) F.J. Herm. The soybean, *G. max* (L.) Merr., and its wild progenitor *G. soja* Sieb. and Zucc., together make up the subgenus *Soja*. Both species are annual and diploid with 2*n*=40, and hybridization between them can be readily effected. Together they form the primary gene pool of the cultivated soybean.

The subgenus *Glycine* comprises seven wild perennial species: *Glycine canescens* F.J. Herm., *G. clandestina* Wendl., *G. falcata* Benth., *G. latifolia* (Benth.) Newell and Hymowitz, and *G. latrobeana* (Meissn.) Benth. are diploids (2*n*=40) native to Australia; *G. tabacina* (Labill) Benth. is predominately tetraploid (2*n*=80) with occasional diploids, and distributed in Australia, Taiwan, and the Ryukyu Islands, as well as several countries in the South Pacific; and *G. tomentella* Hayata represented by tetraploid (2*n*=80) forms in China (Taiwan), the south coast of China and northern Philippines, and diploid, tetraploid, and aneuploid (2*n*=38, 40, 78, 80) forms in Australia. From a taxonomic standpoint the members of the subgenus *Glycine* also are candidates for gene exchange with the soybean, and therefore potentially useful for broadening the germplasm base of the crop. Screening of perennial *Glycine* germplasm has been cursory owing to the lack of experimental material, but preliminary investigations have shown that the perennial species carry resistance to diseases such as soybean rust, yellow mosaic virus, and powdery mildew. Physiological traits exhibited by perennial material such as drouth tolerance, salt tolerance, and day neutrality also may be of potential use.

At the University of Illinois at Urbana-Champaign, the living collections of wild perennial *Glycine* species number about 250 accessions, and a program of morphological, cytogenetic, and biochemical analysis is in progress.

Discussion

R. Palmer asked if an accession of *G. tabacina* exists with a chromosome number of 2*n*=120.

T. Hymowitz stated that one did exist and was found in one plant from Australia. It was not found until after it had been grown in the greenhouse at Urbana, so it is not known whether it was in the original sample or was a mutation which occurred in the greenhouse. All other *G. tabacina* accessions have a chromosome number of 2*n*=80. When 2*n*=120 was crossed with 2*n*=80, segregates were found which ranged from 2*n*=99 to 2*n*=122.

R. M. Goodman asked about the cytogenetics of the *G. max.* x *G. tomentella* cross.

T. Hymowitz responded that the F_1 obtained by using a *G. tomentella* accession with 2*n*=80 had 60 chromosomes but was sterile. Using colchicine the chromosome number has been doubled.

Wang Jin-ling stated that the collection of species related to domesticated soybeans is important. He asked which character in the perennial species might be most useful if transferred to *G. max.*, and if genetic variability for yield existed in the perennial species which might be useful in soybeans.

T. Hymowitz replied that rust resistance was the most useful characteristic in the perennial species and that these species would not be useful for increasing yield.

R. M. Goodman asked if there are traits in the perennial species which are not known to occur in *G. max*.

T. Hymowitz said that these species have been collected only recently and not yet thoroughly evaluated, so it is too early to answer that question.

R. M. Goodman asked about the collection of perennial species in China.

Wang Jin-ling said they had little knowledge of other species except *G. soja*.

T. Hymowitz is professor of plant genetics, UIUC.

There are reports of *G. tabacina* and *G. tomentella* in east-central China but these have not been confirmed.

T. Hymowitz stated that more collections are needed from southern China and some South Pacific islands.

Ma Rhu-hwa asked if tissue culture was being used with the interspecific hybrids. T. Hymowitz replied that they were not using tissue culture but *in vitro* ovule culture.

R. L. Bernard asked if initiation of pods had occurred with all perennial species when crossed with *G. max*. T. Hymowitz answered that certain accessions within each species are better parents for interspecific crosses but that pod initiation had occurred with all species except *G. latrobeana*.

W. R. Fehr asked about the possibilities of cooperative exploration with the Chinese to collect perennial *Glycine*.

Ma Rhu-hwa stated that someday the Chinese would like to come to work with T. Hymowitz at UIUC.

W. Fehr asked who in China would do the work with the perennial *Glycine*.

Wang Jin-ling said the Chinese workers would be in botany and not soybean scientists.

T. Hymowitz asked if the present delegation could contact the appropriate botanists.

Ma Rhu-hwa replied that they would be in the Botany Institute of Scientific Sinica.

R. L. Bernard suggested that since the soybean breeders in Jilin province had a winter nursery on Hainan Island perhaps they could look for perennial species on that island.

Wang Jin-ling said that would be possible.

T. Hymowitz stated that there are no reports of perennial species on Hainan Island but that they are known to occur in Taiwan, China, and islands to the south.

Germplasm Collection, Management, and Evaluation: The Subgenus *Soja*

RANDALL L. NELSON AND RICHARD L. BERNARD

The USDA Soybean Germplasm Collection is divided into two sections. The southern portion contains all *Glycine max* accessions of maturity Group V or later and is maintained at Stoneville, Mississippi. The northern portion contains perennial *Glycine*, *G. soja*, a genetic collection, a named-cultivar collection, and *G. max* accessions of maturity Group IV and earlier. The current totals in the collection are as follows:

Glycine max	9,200
Glycine soja	560
Genetic collection	400
Domestic named cultivars	270
	10,430

This is a working collection and thousands of seed lots are distributed each year to scientists around the world. The seed supply is stored in a controlled environment of approximately 30% relative humidity and 10°C. Under these conditions, seed longevity can be maintained in excess of 10 years.

All *G. max* accessions are maintained as pure lines. The first time a new introduction is grown several individual plants are harvested. The following year the progeny are compared. If all progeny of the new introduction are identical, only one row is harvested and added to the collection. If the progeny rows are not identical, enough rows will be harvested to sample the diversity that is present. By having all accessions as pure lines, the collection is easier to maintain and the risk of permanent contamination either through mechanical mixtures or cross pollination is reduced. It also simplifies evaluation and facilitates the utilization of the germplasm.

Germplasm evaluation is conducted by many scientists throughout the country. Information on disease and insect resistance, chemical composition of the seed, and other specialized traits is gathered by interested specialists in those areas. Basic descriptive and agronomic data are gathered at the location of the germplasm collection. On most accessions data are collected on more than 25 traits which describe the line and help to determine its usefulness in breeding, genetics, or other scientific research.

DISCUSSION

Wang Jin-ling asked if discarded breeding lines in the U.S. were maintained in the germplasm collection.

R. L. Nelson replied that they were not but may be kept by the breeder who developed the line.

Ma Rhu-hwa stated that many of the land races from China should be kept in the original form as a mixed population rather than as pure lines.

R. L. Bernard emphasized that many pure lines may be taken from some seed lots to sample the diversity. He reiterated the need for having pure lines so that inadvertant mixtures can be removed or so that less-adapted genotypes are not lost because of their inability to compete in a mixed population.

Sun Huan asked if the original names of introductions were preserved.

R. L. Nelson stated that they were whenever possible but that many seed lots were received without any identification even though they may have had a name in the country of origin.

R. L. Bernard added that he will publish a listing of all the soybean introductions into the U.S. which are still preserved. The publication will contain all of the information which came with each introduction.

R. L. Nelson is research geneticist, U.S. Department of Agriculture, and assistant professor of plant genetics, UIUC; R. L. Bernard is research geneticist, U.S. Department of Agriculture, and professor of plant genetics, UIUC.

Wang Jin-ling stated that E. E. Hartwig received soybeans from Dr. Buck which he had collected while in Nanjing, so the U.S. may have most of the soybeans from central and south China.

H. E. Kauffman asked about the status of the Chinese soybean germplasm collection.

Wang Jin-ling answered that after 1949 many soybean collections were made and maintained at the provincial level. The total number of accessions in all the collections may be 6,000 to 7,000, but they have been studied little.

H. E. Kauffman asked if there were plans for cooperation among the provinces.

Wang Jin-ling replied that it was just beginning.

Ma Rhu-hwa stated that under the new National Institute of Agriculture there is a Bureau for Agricultural Germplasm. It is responsible for germplasm collection in all crops and active collecting now is under way.

R.L. Bernard asked if many provincial collections had been lost since the 1950's.

Wang Jin-ling and Ma Rhu-hwa replied that they are still kept even in areas where soybeans are unimportant but some collections have been lost.

Ma Rhu-hwa stated that research centers for soybeans now are being organized.

W. Fehr suggested that we need opportunities for extended visits by U.S. specialists in China working with Chinese scientists.

R.L. Bernard added that we need additional germplasm to help solve problems unique to the U.S. so that an exchange of germplasm also is needed.

Breeding for Soybean Pest Resistance

CECIL D. NICKELL

The development of pest-resistant soybean cultivars and germplasm has been emphasized in research conducted by scientists at the University of Illinois at Urbana-Champaign (UIUC). Although many pathogens and insects cause damage to soybeans in Illinois, only the pests studied in our research programs will be discussed.

The foliar pathogens and sources of resistance used in our research program are: *Septoria glycines* (brown spot), which can cause 15% reduction in yield but resistance has not been found; *Peronospora manshurica* (downy mildew), for which resistance from Kanro and PI 88788 has been used in the development of the new cultivars Union and Fayette; *Pseudomonas syringae* pv. *glycinea* (bacterial blight) resistance appears in many cultivars grown in northern U.S.; *Xanthomonas campestris* pv. *phaseoli* (bacterial pustule) resistance comes primarily from one source, CNS, and is found in many cultivars including Williams.

Root pathogens affect soybean yields in Illinois. Resistance to *Phytophthora megasperma* Drechs. f. sp. *glycinea* (Phytophthora rot) comes from several sources, including Mukden ($\underline{Rps_1}^a$), Sanga ($\underline{Rps_1}^b$), Arksoy ($\underline{Rps_1}^c$), Kingwa ($\underline{Rps_1}^k$), CNS ($\underline{Rps_2}$), and Tracy ($\underline{Rps_1}^b$, $\underline{Rps_3}$). Williams 79 ($\underline{Rps_1}^c$), Williams 82 ($\underline{Rps_1}^a$), and Union ($\underline{Rps_1}^a$) are new cultivars that resulted from the transfer of single genes into the cultivar Williams. *Phialophora gregata* (brown stem rot) resistance, used in three new cultivars from Iowa (BSR 301, BSR 302, and BSR 201), came from PI 84946-2. The initial transfer of resistance from PI 84946-2 to adapted germplasm was made by the USDA at UIUC. Newer sources of resistance now used include PI 86150 and PI 90138.

Seed quality is a problem in the southern half of Illinois. Pathogens associated with poor seed quality include *Phomopsis* spp. (pod and stem blight) and *Cercospora kikuchii* (purple seed stain). Resistance to *Phomopsis* spp. has been reported in PI 181550. No specific source of resistance has been reported for *C. kikuchii*.

Viruses are present in farmer fields and may cause yield losses. PI 424131 and PI 96983 are being studied in the laboratory and field for resistance to soybean mosaic virus (SMV).

Soybean cyst nematode (*Heterodera glycines*) resistance has received considerable research effort. Peking was used as the source of resistance in the cultivar Franklin, and PI 88788 as the source of resistance for Fayette.

Breeding methods used in cultivar development to incorporate pest resistance include backcrossing and recurrent selection. Improved cultivars have been developed, such as Williams 79 and Williams 82, through the backcross procedure to transfer one gene for Phytophthora rot resistance. Recurrent selection is used when several genes control resistance, such as resistance for soybean cyst nematode in the cultivar Fayette.

Greenhouse evaluation of resistance has been used in soybean cyst nematode, Phytophthora rot, and SMV, while field evaluation has been important in foliar and other root pathogens.

C. D. Nickell is associate professor of soybean breeding, UIUC.

Inheritance of Resistance to Soybean Pod Borer in Soybeans

ZHANG ZI-JIN AND FU CHENG-QUAN

The soybean pod borer, *Leguminivora glycinivorella* Mats. (Lepidoptera: Tortricidae), is an important pest of soybeans in northeast Asia. Its widespread distribution includes the northern parts of China, Korea, Japan, and maritime regions of U.S.S.R. It is a severe pest in the plains of east China. Seed damage in soybean fields usually is 10% to 20% and may be greater than 40% for some susceptible cultivars when severely attacked. Certain insect-resistant cultivars have been developed by soybean breeders, and use of these has helped control pod borer damage. However, there are few data available to soybean insect resistance breeding programs about the inheritance of resistance to the pod borer. This report covers the primary results of qualitative genetic analysis for resistance to pod borer of representative soybean combinations in our soybean insect resistance breeding program.

MATERIALS AND METHODS

Three soybean crosses were made with parent cultivars resistant and susceptible to soybean pod borer. Two of the three combinations were reciprocal crosses. The combinations and the source and characters are presented in Tables 1 and 2.

Experiments were conducted at the soybean breeding nursery of the Jilin Academy of Agricultural Science, Gong Zhu Ling, Jilin. The F_0 seeds of the three crosses were produced in 1959, and F_1 through F_4 progenies were planted successively from 1960 to 1963. Each progeny was planted in a single row 4.5 m long with 60 cm between rows and 25 cm spacing in the rows. At the beginning and middle of the progeny rows, two parent cultivars of each combination were planted. Pod borers were not released, but natural pod borer damage was observed. The characters evaluated included damaged seeds per plant, plant height, branch number, node numbers on main stem, yield, and 100-seed weight. Thirty to 40 plants were evaluated in F_1, more than 600 plants in F_2, and about 1,500 plants in F_3 and F_4 generations.

Formulae used for estimates were:

1. Heterosis (%) $= \frac{F_1}{Mp} \times 100$

2. Heritability (%) $= \frac{V_{F_2} - 1/2(V_{p_1} + V_{p_2})}{V_{F_2}}$

Table 1. Types of soybean crosses

Crosses	Types of resistance
Man Cang Jin x Li Wai Qing	Susceptible x resistant
Man Cang Jin x Jilin No. 3	Susceptible x resistant
Jilin No. 3 x Man Cang Jin	Resistant x susceptible

Zhang Zi-jin is Deputy Director of the Soybean Research Institute, Jilin Academy of Agricultural Science, People's Republic of China; Fu Cheng-quan is with the Jilin Academy of Agricultural Science, People's Republic of China.

Table 2. Sources and characters of soybean parent cultivars

Cultivar	Sources	Characters
Man Cang Jin	Gong Zhu Ling Agricultural Experiment Farm, released in 1941	High, stable yields, high oil content, wide adaptation, susceptible to pod borer, widely grown
Li Wai Qing	Farmer cultivar in the south-central part of northeast China	More flowers and pods, good yield potential, an ancient local cultivar
Jilin No. 3	Jilin Academy of Agricultural Science	Strong stem and good resistance to lodging, suitable for intercropping with maize, high resistance to pod borer, a widely grown soybean cultivar in Jilin Province

3. Coefficient of correlation (r) =

$$\frac{xy - N\bar{x}\bar{y}}{(x^2 - N\bar{x}^2)(y^2 - N\bar{y}^2)}$$

RESULTS AND DISCUSSION

Inheritance of Insect-Resistance in F_1 Generation

Data on percentage of damaged seeds in the F_1 generation and its parents are illustrated in Figure 1. The percentage of damaged seeds for all three F_1 generation combinations was between those of each of the two parents, but slightly higher than the expected mid-parent value and tended toward the susceptible parent. No significant difference was found between reciprocal crosses and their F_1 resistance. Thus, the character for soybean pod borer resistance is controlled by the nucleus and not the cytoplasm.

Variation of Insect Resistance in F_2 Generation

The segregation of insect resistance in F_2 populations was highly significant (Fig. 2). The segregation range of seed damage per plant was from 5% to 75%, the highest 15

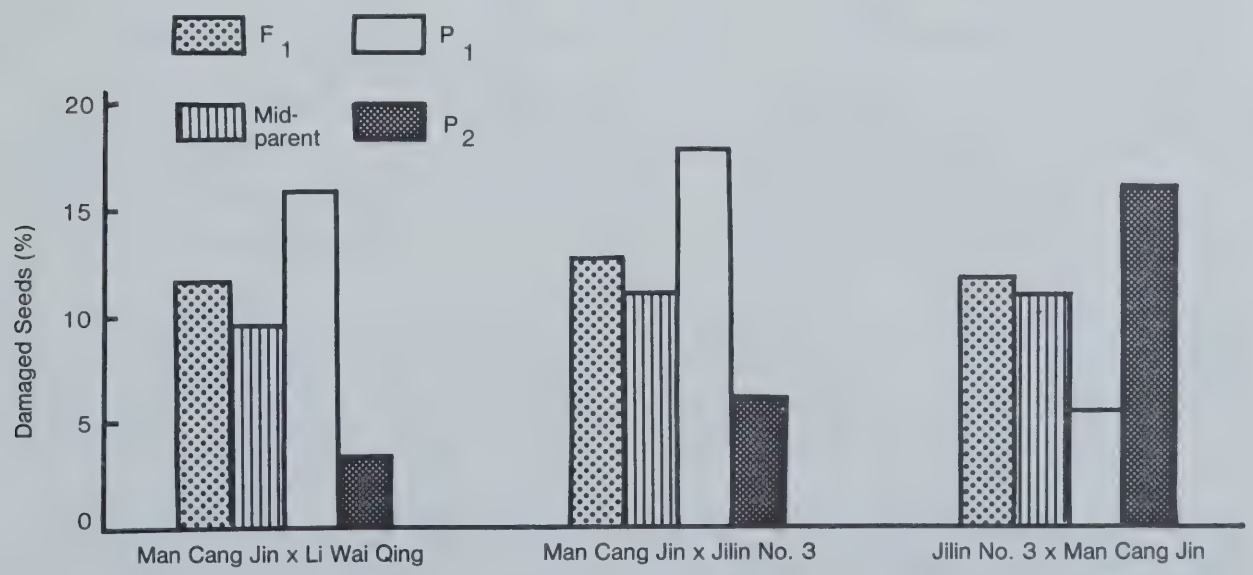


Figure 1. Percentage of seed damage in the F_1 generation and its parents.

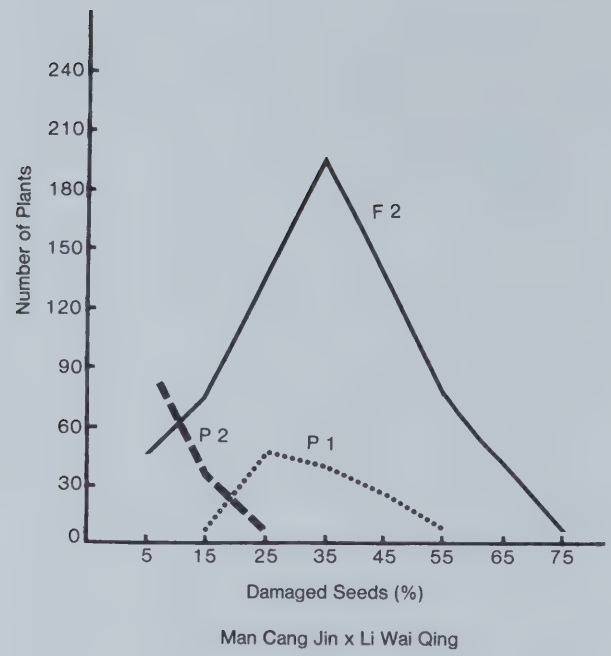
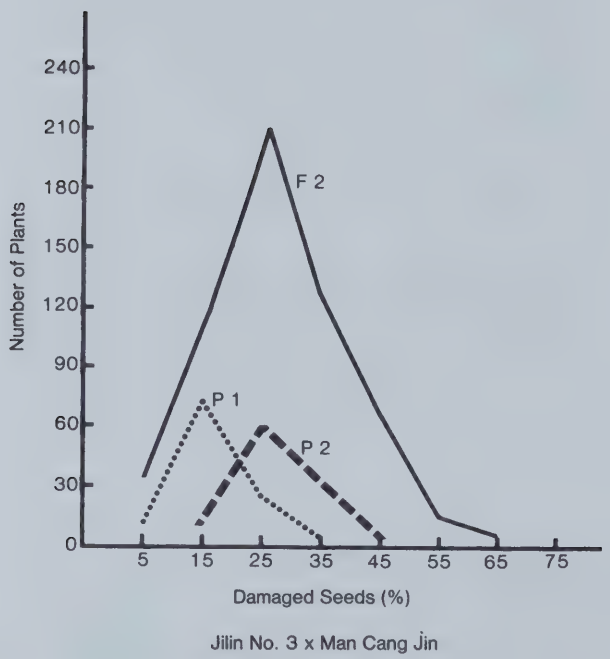
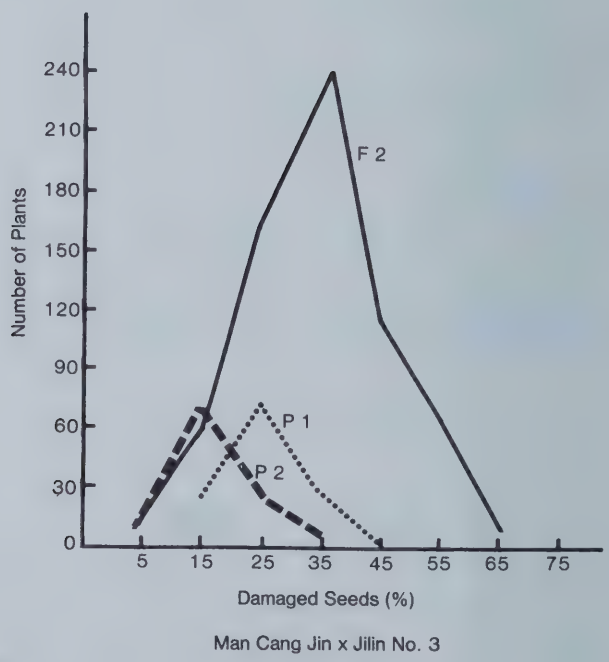


Figure 2. Segregation of insect resistance in F_2 populations in three crosses.





times the lowest. The expansive segregation showed a successive variation of numerous microdifferences, and the frequency distribution curves of the three combinations had a single peak. This pattern was similar to the inheritance pattern of a multiple gene controlled character.

All three combinations showed transgressive segregation, but most of the transgressive individuals tended toward the susceptible parent. Each of the three combinations had a transgressive segregation range of 20% damaged seeds. The number of transgressive individual plants differed among combinations. Man Cang Jin x Jilin No. 3 combination had the greatest number of transgressive plants, which was more than 15% of the F_2 population; Jilin No. 3 x Man Cang Jin had the least (8%); and Man Cang Jin x Li Wai Qing was intermediate, with 10% of its F_2 population being transgressive plants (Fig. 2). This susceptible

transgressive segregation suggests that the frequency of highly insect-resistant progenies from the combination between resistant and susceptible soybean variation is very low. Thus to breed for pod borer resistance it is necessary to use resistant parents, to take resistance x susceptible combinations for breeding population, and to maintain a large F_2 population for selecting segregates.

Heritability of Insect Resistance

The heritability of insect resistance estimated by variance analysis for F_2 and F_3 generations is shown in Table 3. The heritability values of F_2 plants in the three combinations were 83.3%, 69.8%, and 77.1%, respectively, with a mean of 76.6%. This showed that heritability of insect resistance in the F_2 generation generally was higher. Heritability in the F_3 was lower than in F_2 because F_3 had a significantly low genetic variance. Therefore, selection for insect resistance can be conducted effectively among the early generations of their progenies. Insect resistance between early and late generations showed a close correlation. If the F_2 generation population was insect-resistant, so were F_3, F_4, and F_5. It was found that insect-resistant lines had low percentages of damaged seeds. Insect-susceptible F_2 populations had high percentages of damaged seeds and gave fewer insect-resistant lines than the later generations. This suggests that the F_2 generation can be used to select insect-resistant combinations as well as plants with favorable agronomic characters within selected combinations. Insect-resistant lines can be selected from the F_3 and later generations.

Correlation of Resistance

Selecting resistant soybean plants in the field is difficult. Is it possible to select resistant plants indirectly with the aid of other characters? We measured the relationship among progenies of various F_2 generations for the relationship between the percentage of seed damage and maturity (Table 4). The level of seed infestation in F_2 segregated individuals differed at different maturity dates. In early- (September 2-7) or late-maturing (September 27) lines, injury levels were lighter than for lines maturing September 12 to 17. "Light-heavy-light" infestations occurred, but the most serious injury occurred on September 12. The results were similar to those of earlier-maturity selected lines and in cultivars grown in the past. Thus, soybean maturity is strongly influenced by the amount of seed damage, so that selecting resistance among the progenies near maturity is reliable. Correlations between seed damage and other characters were obtained (Table 5).

The percentage of seed damage and plant height were correlated significantly, but it may be a phenomenon caused by environmental conditions (Table 5). The percentage of seed damage and 100-seed weight of combinations and progenies were significantly correlated. When we consider the foregoing

Table 3. Broad sense heritability (%) of insect resistance based on F_2 and F_3 individual plants

Crosses	Generation	No. of observed plants	Genetic variance	Environmental variance	Heritability (%)
Man Cang Jin x Li Wai Qing	F_2	672	189.5	43.8	83.3
	F_3	1,520	49.5	38.9	56.0
Man Cang Jin x Jilin No. 3	F_2	671	92.9	42.4	69.8
	F_3	1,520	20.1	46.0	30.4
Jilin No. 3 x Man Cang Jin	F_2	657	112.8	42.1	77.1
	F_3	1,520	40.4	26.5	60.4
Means	F_2	666	131.7	42.8	79.6
	F_3	1,520	36.7	37.1	48.9

facts, it is apparent that larger seed size should not be selected for breeding insect-resistant cultivars. The correlation coefficients between the percentage of seed damage and number of branches, number of nodes on main stem, and yield were not constant or not significant.

Table 4. Relationship between F_2 percentage of seed damage and maturity, 1961-1963

Crosses	Plant lines	No. of plants	% of F_2 seed damage Sept. 2	Sept. 7	Sept. 12	Sept. 17	Sept. 22	Sept. 27	Means
	1	118	15.6	12.3	42.2	37.4	25.5	34.6	29.5
Man Cang Jin	2	130	18.0	51.9	50.7	39.1	45.0	21.4	37.9
x	3	224	16.9	18.8	33.0	29.9	37.2	34.7	28.4
Li Wai Qing	4	220	19.4	33.0	45.7	46.5	44.0	20.3	34.8
Means (total)		672	17.4	29.0	42.9	38.0	37.9	27.7	
	1	156	29.7	32.1	41.4	37.9			35.3
Man Cang Jin	2	193	28.4	35.0	40.0				34.5
x	3	169	32.9	34.5	34.8				34.1
Jilin No. 3	4	153	30.5	32.9	41.6	34.7			35.7
Means (total)		671	30.4	33.6	39.5	36.3			
	1	203	28.9	33.4	24.7	24.9			30.5
Jilin No. 3	2	125	26.1	28.9	44.9				33.3
x	3	151	14.3	18.0	27.3				20.0
Man Cang Jin	4	178	16.5	20.6	25.3	25.2			21.1
Means (total)		657	21.5	25.2	30.6	25.0			

Table 5. Correlations (r) between percentage of seed damage and several characters

Characters	Man Cang Jin x Li Wai Qing			Man Cang Jin x Jilin No. 3			Jilin No. 3 x Man Cang Jin		
	F_2	F_3	F_4	F_2	F_3	F_4	F_2	F_3	F_4
	(Correlation with percentage of seed damage)								
Plant height	0.0257	0.4205**	0.2605**	-0.0145	0.2657**	0.3724	0.1542	0.4334**	0.6802**
No. of branches	-0.2856**	-0.3687**	0.0181	0.0954	0.0724	0.3250**	0.1633	-0.0721	-0.0581
Nodes on main stem	-0.1786	-0.4558**	0.4489**	0.0860	0.1079	-0.3132**	-0.0700	0.1972	0.5264**
Yield	-0.2193	-0.0578	-0.1603	0.3510**	0.2803**	-0.0126	0.0433	0.2630	0.1493
100-seed weight	-0.0535	0.1668	0.2565**	0.2281	0.4848**	0.7438**	0.1935	0.3487**	0.3762**

**Significant at 1% probability level.

DISCUSSION FOLLOWING THE PRESENTATIONS BY C. D. NICKELL AND ZHANG ZI-JIN

Ma Rhu-hwa asked if PI 96983 and PI 424131 were the only two sources of resistance to soybean mosaic virus (SMV).

R. L. Bernard said that other sources also were being used.

R. M. Goodman added that some strains of SMV from China attack the sources of resistance being used in the U.S.

Ma Rhu-hwa asked about breeding methods for SMV resistance.

R. L. Bernard said that the known genetics indicated single gene resistance so that the trait could be incorporated into improved cultivars by backcrossing or other breeding methods. The common commercial cultivars are susceptible to SMV but not severely affected. Yield tests with near isogenic cultivars show no yield advantage for SMV resistance.

R. M. Goodman reported that field inoculation with some SMV isolates will severely affect some cultivars. Many factors influence disease development, but all commercial cultivars might be severely affected if infected at the right stage by the right aphid.

R. M. Goodman asked about the virus situation in Iowa.

W. R. Fehr reported that Hill had developed techniques for determining seed infection but that Fehr did not think that SMV was a problem.

Gai Jun-yi asked where the virus-resistant cultivars Buffalo and Kwang-kyo were developed.

R. L. Bernard stated that Buffalo (PI 424131) was developed in Zimbabwe and that Kwang-kyo (PI 406710) was developed in South Korea. PI 96983 also is from Korea.

Wang Jin-ling asked if there was any information on resistance to Sclerotina stem rot.

T. G. Isleib said it was a problem on dry beans but not on soybeans in Michigan.

R. L. Bernard said it was sporadically a problem but not often serious.

M. Kogan asked if the mechanisms of pod borer resistance had been studied.

Zhang Zi-jin said that a hard pod which was difficult for the larva to penetrate may be the major factor of resistance. Larval mortality may be as high as 80% with resistant cultivars but only 30% with susceptible ones.

Wang Jin-ling said only one generation of pod borer occurs each year.

M. Kogan cautioned that reported effects of maturity on pod borer resistance may be because certain cultivars escape pod borer damage due to the timing of pod development.

Wang Jin-ling added that glabrous cultivars provide resistance to the pod borer.

Zhang Zi-jin said that pod borer eggs are laid in early to mid-August.

Breeding for Soybean Yield and Agronomic Traits

RICHARD L. BERNARD

Improved grain yield per hectare has been the main goal since formal soybean breeding was begun in Illinois over 40 years ago. Pest resistance has received increasing attention in recent years, but most improved cultivars in the midwestern U.S. are released because of improved yield. Other agronomic traits in which major improvement has been made are resistance to lodging and shattering, and improved seed quality and composition.

Because soybeans are planted close together in widely spaced rows and harvested mechanically, a high degree of lodging resistance is necessary. Most cultivars will lodge when growing conditions are good, so further improvement is sought constantly.

Delayed harvest, which often occurs in the midwestern U.S. because of weather, can result in yield loss through shattering either before or during harvest. Most midwestern U.S. cultivars have satisfactory shattering resistance, but attention must be paid to this trait to avoid regression to the more shattering-prone type. Improvement is being made in the ability to produce good-quality seeds under adverse environmental conditions, and the oil and protein content of potential cultivars is monitored to ensure suitable levels.

All soybean cultivars now grown in the midwestern U.S. were developed by artificial cross-pollination followed by selection until true-breeding lines were obtained. Parent lines are chosen to combine good traits of one with those of another or simply to combine two good cultivars with the hope of producing a better one. Traditional plant-to-row pedigree selection sometimes is used, but more often bulk population advance (single-seed or single pod descent) is used through the early segregating generations (F_2 to F_5) since it takes less labor and space. Such bulk populations are often grown in a winter nursery in the tropics to reduce the time it takes to produce breeding lines.

The backcross breeding method adds a simply inherited trait such as disease resistance to an otherwise well-adapted cultivar. Advantages of this method are the small populations necessary, the greater speed of development, the relatively certain and predictable result, and the minimizing of yield-testing. We grow two generations in the greenhouse in the winter, thus getting three per year. Recent cultivars such as Corsoy 79 and Williams 82 with single genes for Phytophthora rot resistance, and Will with a single gene for semi-determinate stem, were developed by this method.

Observation and selection often is successfully done in early generations for traits such as time of maturity, shattering resistance, seed quality, and perhaps even lodging resistance and yield where differences are very large. At the F_4 to F_6 generation (F_3 for the backcross method) lines are bulked and testing begins. Typical yield tests are in four-row plots (middle two for harvest, 75 cm row spacing), 3 to 5 meters long, although we sometimes measure yield in an initial screening test in small one-row plots. Testing is done at several locations in Illinois for two to three years with early lines (maturity Group II) being tested in the north and central part, Group III in central Illinois, and late lines (Group IV and sometimes V) in southern Illinois.

The best lines are selected and entered in a cooperative regional "Preliminary Test" of the appropriate maturity group. These lines are grown at six to eight locations in various states. After one year, the best lines are advanced to the "Uniform Test." After two to four years of further testing, the best ones are released for commercial production.

These are very important tests since they constitute the final testing before a variety goes to the farmer. They give good data in a short time on the performance of cultivars under a wide range of environments

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since the tests are grown over the very wide area in which each maturity group is adapted. In 1981 the six tests of the northern Uniform Tests (one test for each maturity group OO to IV) had 94 soybean entries (plus 176 preliminary entries), involving 35 researchers in 15 U.S. states and Canada at 51 locations (seven to 22 locations per maturity group). Over the last 40 years from these tests and those in southern U.S. have come most of the successful commercial cultivars grown in the U.S.

DISCUSSION

Wang Jin-ling reported on the procedure for developing and testing new soybean cultivars in Jilin and Heilongjiang provinces. They use the pedigree method of breeding to the F_4 generation. Preliminary tests are conducted by each institution with the best lines advanced to regional tests. The provinces are divided into testing regions based more on temperature than latitude, especially in the northern area. They collect data on yield, lodging, and disease resistance. After two to three years of testing, the data are reviewed by a committee that determines which cultivars will be released and where they will be released. A cultivar must be certified by this committee in order to be sold.

Ma Rhu-hwa reported on cultivar testing in the Chang Jiang (Yangtze) River region. Tests are begun on the local level with the best selections advanced to provincial tests. The best lines from several provinces in the River Valley Region are entered in a cooperative interprovincial testing program. These results are used to select cultivars for release and to identify areas where new cultivars are best adapted.

Zhang Zi-jin gave some history of cultivar development in China. There are three major soybean growing regions: the northeast, the Huanghe River valley, and southern China. In the 1950's and 1960's, the three provinces of northeast China cooperated in regional tests and released many cultivars. Because the three provinces are at different latitudes, the cooperative test was discontinued but some cultivars still are jointly tested. In the other two areas, regional testing was begun in the early 1960's. The Ministry of Agriculture is in the process of reviewing the soybean testing procedure.

Wang Jin-ling asked about private soybean breeding companies in the U.S.

R. L. Bernard responded that probably less than 20% of the hectarage nationwide is planted to private soybean cultivars.

W. R. Fehr stated that private companies in Iowa had grown faster than in any other state, and their cultivars have been very successful. Between 35% and 50% of the soybean hectarage in Iowa is planted to private cultivars.

Wang Jin-ling asked about the use of blends in the U.S.

R. L. Bernard replied that public institutions generally did not recommend blends but that they were being sold by some private companies.

W. R. Fehr added that blends are recommended to help reduce losses due to iron deficiency chlorosis in Iowa.

Qualitative Soybean Genetics and Cytogenetics

HENRY H. HADLEY

The distinction between quantitative and qualitative characters is somewhat arbitrary, particularly when one compares their degrees of importance. Furthermore, variation in quantitative characters frequently is associated with, if not dependent upon, variation in one or more qualitative characters. Thus, even though quantitative characters may occupy a major portion of the soybean breeders' attention, qualitative characters can be quite important in their breeding program.

Qualitative characters and the major genes affecting them can be important for several reasons. They may (1) have enough economic importance to be selected for directly, e.g., hilum color or absence of the Kunitz trypsin inhibitor; (2) have an indirect effect on a desirable economic character, e.g., Phytophthora root rot resistance causing an increase in seed yield; (3) facilitate basic physiological studies, e.g., noduleless genotypes and their effects on nitrogen metabolism; (4) help the cytogeneticist map the soybean genome; and (5) facilitate the development of special techniques for obtaining pure lines or controlled hybrids on a large scale, e.g., male sterility for producing F_1 hybrids.

The last three reasons are valid whether the qualitative character expression is good or bad from a commercial production standpoint. The same is not true for the first two reasons. Characters of economic importance often are affected by both polygenic systems and by major genes that have such large effects they produce Mendelian variation. In some cases a major gene may have a primary effect that would seem desirable, e.g., a gene producing dwarfism that should increase lodging resistance, but at the same time produce a secondary effect such as seed yield reduction because fewer pods are set or pods are too close to the ground. The expression of such a gene might be "improved" by selecting a more favorable genetic background that might reduce the dwarfing effect and increase pod set so that the new result would be favorable. But the breeder's problem then becomes a quantitative one and the breeder might ask whether selection for shorter plant height based on a polygenetic system might not have been a better approach in the first place.

Genes that attract the breeder's attention because of their major effects on qualitative characters probably should be evaluated before the breeder invests heavily in attempts to use them. One method of evaluation is to develop near isogenic lines and to compare the two forms, AA and aa, in performance tests. Such pairs of lines can be developed in any of three ways: (1) by obtaining mutants in a population with the normal or standard genotype, e.g., a dense pubescent plant in one or more cultivars with "normal" pubescence; (2) by backcrossing to place a mutant gene in one or more genetic backgrounds; and (3) by selfing heterozygotes (Aa) in the F_2 and later generations of crosses between the mutant type and one or more normal lines ultimately saving AA and aa pairs representing different F_2 families. Since a gene performs differently in different genetic backgrounds or environments and in different nongenetic environments, the "mutation" method of developing near isogenic pairs usually results in too limited a sampling of genetic backgrounds to justify a generalization as to the value of a gene. The backcrossing method can provide a better sample of backgrounds if several recurrent parents are used and thus support a wider generalization. The third method also can lead to a wider range of backgrounds, depending upon the potential genetic variation represented by the hybrids made. The latter two methods lead to differences in short chromosome segments linked to the A,a locus. The test should still be accurate enough for the breeder to decide whether the good effects of the mutant gene outweigh its possible bad effects.

H. H. Hadley is professor of plant genetics, UIUC.

R. L. Bernard, U.S. Department of Agriculture and UIUC, has developed numerous near isogenic soybean lines by the backcross method, many of which are in both Harosoy and Clark genetic backgrounds. More recently he has used other backgrounds as well. These lines are in the soybean germplasm collection and have been used by breeders, geneticists, pathologists, and others from many geographical areas. Work with qualitative characters caused by major genes has been or is being done at UIUC in selecting for pest resistance, time of maturity, plant morphology, seed chemical composition, ability to nodulate, variation in fertility, and other phenotypic classifications. Some of this work has led to new cultivars. Other work has added to our knowledge of the soybean plant.

Only a limited number of people have dealt with soybean cytogenetics. This area of research, however, is helpful in studies of reduced fertility, whether within the cultigen or in interspecific hybrids. Work at UIUC is being done in both these areas. Routine chromosome counts and studies of meiosis in the wild relatives of *Glycine max* continue to be conducted as the wild relatives' portion of the germplasm collection is accumulated and characterized. Cytogenetic studies associated with genetic engineering and tissue culture techniques may increase as such techniques are developed and possibly be used on a large scale.

Studies on the Genetic Variability of Hybrid Generations of Soybeans

MA RHU-HWA AND GAI JUN-YI

The objectives of studying soybean hybrids were to investigate the amount of hybrid vigor; determine the general combining ability (gca) and specific combining ability (sca) of cultivars as a means of selecting parents for crosses; and evaluate additive and nonadditive gene action in F_1 and later generations.

MATERIALS AND METHODS

Five cultivars, Beeson and SRF 400 from the U.S., and Nanjing 493-1, Nanjing 1138-2, and Xu Zhou 424 from Jiangsu, China, were used as parents. In 1974, seeds were obtained from ten crosses. In 1975, F_1 seeds and their parents were planted in a randomized complete-block design with three replications. There was 67 cm between rows and 17 cm between plants in a single-row plot of 10 plants. In 1976, the F_2 seeds and parents were planted in a randomized complete-block design with three replications. Each plot had three rows of 10 plants with 67 cm between rows and 11 cm between plants in a row. Yield was obtained from the center row, and other agronomic characters were measured from 30 plants randomly selected from the border rows. In 1978, the F_3 and F_4 generations were planted in a design similar to that used in 1976.

Agronomic characters selected for study were plant height, days to flowering, days to maturity, height of lower pods, number of branches per main stem, number of pods per plant, number of seeds per plant, number of nodes per main stem, number of pods per node, number of seeds per pod, percentage of aborted seeds, seed size (weight in g per 100 seeds), seed yield per plant, and yield per plot.

For each cross, we calculated mid-parent heterosis (mp%) as $100(F_1 - mp)/mp$ where mp equals 0.5 (low parent + high parent), and high parent heterosis (hp%) as $100(F_1 - hp/hp)$. For each character, the mean mp% and hp% of the ten crosses were determined for F_1 and later generations.

The ten crosses were divided into two groups. One group included six crosses with one parent from the U.S. and one from the PRC, and the second group included three crosses between only PRC cultivars and one cross between two U.S. cultivars. The heterosis of these two groups was compared to determine any difference between parents from different genetic origins.

From the heterosis of the F_1 and later generations, we could ascertain if there was any yield loss from inbreeding. A combining ability analysis was carried out by use of Griffing method II, assuming a random model for each character.

RESULTS

Heterosis and Inbreeding Depression of Successive Generations Following Hybridization

There was significant heterosis in F_1 (Table 1), as tested by the mean difference method. For example, the mp% of the seed weight per plant averaged 63.8 and hp% averaged 20.9, while for yield mp% averaged 59.1 and hp% 17.2. Plant height displayed significant mp% (17.5) but not significant hp% (3.4). Days to flowering and days to maturity displayed heterosis for earliness. The number of pods per plant, number of seeds per plant, and number of nodes per main stem all showed significant mp% and hp%, but seed size did not. These results show that the possible components of heterotic performance for yield of soybeans are attributable to number of pods, number of seeds per plant, and number of nodes per stem, but are not attributable to seed size. The average hp% for percent of aborted seeds was -45.4.

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Table 1. F_1 heterosis for agronomic characters of soybeans grown in 1975

Characters	Average mid-parent heterosis %	Range for mp%	Average high-parent heterosis %	Range for hp%
Plant height (cm)	17.5**	-3.1 - 35.9	3.4**	-18.5 - 20.6
Days to flowering	-0.6**	-7.2 - 5.4	-15.1**	-24.5 - 0.0
Days to maturity	3.8**	-2.2 - 11.1	-3.9*	-7.9 - 0.2
Height of lower pods (cm)	-11.7	-31.5 - -0.5	-28.2	-50.8 - -3.0
Branches/main stem*	43.8**	-5.5 - 118.2	-6.0**	-41.5 - 41.8
Pods/plant	51.0**	-9.9 - 139.0	11.8**	-40.6 - 74.7
Seeds/plant	63.8**	-13.2 - 176.1	26.0**	-48.1 - 126.8
Nodes/main stem	16.0**	-5.0 - 27.9	3.7**	-5.7 - 21.1
Pods/node	31.9**	-5.8 - 92.6	1.9**	-29.7 - 43.7
Seeds/pod	-1.2	-12.8 - 14.6	-10.7	-27.8 - 10.0
Aborted seed (%)	-30.6**	-55.6 - -2.0	-45.4	-63.5 - -24.6
Seed size (g/100 seeds)	5.3**	-4.6 - 12.0	-2.6*	-16.2 - 8.5
Seed weight/plant (g)	63.8**	-16.6 - 180.7	20.9**	-48.2 - 122.2
Yield (kg/ha)	443.4**	-129.7 - 1362.3	129.3	-365.3 - 921.7

*Significant at 5% probability level.
**Significant at 1% probability level.

The heteroses of F_2, F_3, and F_4 generations are listed in Table 2. We observed that seeds per plant and yield both show a tendency to drop rapidly in mp% and hp%. Yield components (except number of seeds per pod and percent of aborted seeds) changed during selfing, especially the number of pods per plant and number of seeds per plant. Plant height, days to flowering, and maturity were more stable in the consecutive selfing generations. These results show that the yield components, especially pods per plant, seeds per plant, and nodes per main stem, exhibit inbreeding depression. It seems that in soybeans as in maize, F_1 seeds should be used for increasing yield.

The comparison of combining ability of parents in different crosses is shown in Table 3. For yield and its component characters, SRF 400 and Nanjing 493-1 have the best combining ability, Xu-Zhou 424 and Nanjing 1138-2 next, and Beeson the worst.

We placed the ten crosses into two groups according to differences in origin (Table 4). The comparison of yield and five other agronomic characters between these two groups revealed that the crosses between U.S. and PRC cultivars were better than crosses between cultivars from the same country. For example, hp% for U.S. and PRC crosses averaged 19.2 compared with 14.3 for crosses between cultivars from the same country.

The correlation coefficients between F_1 and F_2, F_1 and F_3, and F_1 and F_4 for yield and five other agronomic characters are given in Table 5. Days to flowering and days to maturity were significantly correlated. Yield and its component characters were not correlated, which suggests that F_1 performance cannot be used to accurately predict the performance of a segregating population.

Analysis of Combining Ability and Genetic Parameters of F_1's and Later Generations Following Hybridization in Soybeans

The ten F_1's and five parents were analyzed as randomized block with three replications. The results of the F_1 and later generations are given in Table 6. The genotype mean squares (MS) for the 14 characters in F_1 and F_2 were all significant. However, in F_3, number of branches per main stem and number of pods per plant were not significant.

The analysis of combining ability of the F_1 is given in Table 7. The gca for all characters was significant, indicating additive genetic variability, which is important in all characters in soybeans. The sca of height of lower pods, number of pods per plant, and seed size was not significant. Sca of each of the remaining 11 characters including yield was significant. Thus non-additive genetic variance also existed for most characters of soybeans. The comparisons of MS for gca and sca gave ratios ranging from 2.8 for number of seeds per plant to 63.2 for days to flowering. The MS for gca of all agronomic characters was larger than that of sca. The analysis of F_2, F_3, and F_4 data showed similar results.

Table 2. Average heterosis for agronomic characters in successive selfing generations of soybeans from 1975 to 1978

Characters	Type of heterosis	% for each generation			
		F_1	F_2	F_3	F_4
Plant height (cm)	mid-parent %	17.5**	-	10.2**	15.2**
	high parent %	3.4**	-	4.7**	5.2*
Days to flowering	mid-parent %	-0.6**	-5.3**	-0.3	-0.6
	high parent %	-15.1**	-14.2**	-12.3**	-12.1**
Days to maturity	mid-parent %	3.8**	1.4**	7.1**	1.4*
	high parent %	-3.9*	-2.1**	0.7**	-1.1
Height of lower pods (cm)	mid-parent %	-11.7	-	11.4**	17.9**
	high parent %	-28.2	-	-13.5	-9.9*
Branches/main stem	mid-parent %	43.8**	-	-6.3	8.9
	high parent %	6.0**	-	-13.9	-4.7
Pods/plant	mid-parent %	51.0**	-	0.2	9.8*
	high parent %	11.8**	-	10.3	1.0
Seeds/plant	mid-parent %	63.8**	-	0.4	3.1**
	high parent %	26.0**	-	-10.9	-5.0**
Nodes/main stem	mid-parent %	16.0**	-	4.6**	13.4
	high parent %	3.7**	-	1.4*	7.7
Pods/node	mid-parent %	31.9**	-	-3.7	-0.6
	high parent %	1.9**	-	-7.0	-9.1
Seeds/pod	mid-parent %	-1.2	-	-6.2	-0.2
	high parent %	-10.7	-	-15.2	-9.0
Aborted seeds (%)	mid-parent %	-30.6**	-	-11.3**	23.3*
	high parent %	-45.5	-	-25.7**	-2.0
Seed size (g/100 seeds)	mid-parent %	5.3**	3.4*	5.9	-4.2
	high parent %	-2.6*	-6.3*	-13.7	-10.8
Seed weight/plant (g)	mid-parent %	63.8**	-	-3.5	18.7*
	high parent %	20.9**	-	-9.7	-5.1*
Yield (kg/ha)	mid-parent %	443.4**	152.48*	-14.3	88.4**
	high parent %	129.3**	-124.0	-66.5	-107.5**

*Significant at 5% probability level.
**Significant at 1% probability level.

Additive genetic variance and dominance variance are listed and the ratios of additive genetic variance to total genetic variance are given in Table 7. The range of the ratio was from 38% for number of seeds per pod to 95% for days to flowering. The characters which have a ratio greater than 60% included plant height, number of branches per main stem, number of pods per node, height of lower pods, number of seeds per pod, seed size, days to flowering, and days to maturity. In breeding, these characters could be selected in early generations for their high ratio of additive genetic variance.

The broad sense heritability value (h^2B) and the narrow sense heritability value (h^2N) for all agronomic characters are given in Table 7. When comparing h^2N values of F_1 and later generations for different

Table 3. Average F_1 high-parent heterosis (hp%) for five soybean parents

Characters	Hp% for five parents				
	Beeson	SRF 400	Nanjing 493-1	Nanjing 1138-2	Xu-Zhou 424
Plant height (cm)	-12.6	5.4	1.0	10.4	12.8
Days to flowering	-16.8	-13.1	-15.3	-17.1	-13.3
Days to maturity	-6.0	-2.4	-2.6	-4.4	-3.9
Pods/plant	-26.4	27.1	23.6	14.1	20.5
Seeds/plant	-27.4	43.2	51.4	24.6	38.3
Aborted seeds (%)	-36.5	-44.5	-53.6	-46.3	-46.0
Seed size (g/100 seeds)	-1.9	-2.2	0.9	-12.0	2.1
Seed weight/plant (g)	-27.9	38.7	45.4	13.4	34.9
Yield (kg/ha)	-209.2	242.8	323.6	55.4	233.9

Table 4. F_1 heterosis for U.S. x U.S., U.S. x PRC, and PRC x PRC soybean cultivar crosses when grown in 1975

Characters	Type of heterosis	U.S. x PRC crosses	U.S. x U.S. and PRC x PRC crosses
Days to flowering	mid-parent %	0.1	-1.6
	high parent %	-19.9	-7.9
Days to maturity	mid-parent %	5.3	1.4
	high parent %	-3.1	-5.0
Pods/plant	mid-parent %	63.8	31.8
	high parent %	14.0	8.4
Seeds/plant	mid-parent %	79.0	41.0
	high parent %	26.6	25.2
Seed size (g/100 seeds)	mid-parent %	6.9	3.1
	high parent %	-0.7	-5.5
Yield (kg/ha)	mid-parent %	562.4	265.1
	high parent %	144.2	107.0

Table 5. Correlation coefficients between generations for the agronomic characters of soybean hybrids

Characters	Generations correlated		
	F_1F_2	F_1F_3	F_1F_4
Days to flowering	0.95**	0.87**	0.77**
Days to maturity	0.88**	0.99**	0.79**
Pods/plant	-	-0.06	0.51
Seeds/plant	-	0.04	0.80**
Seed size (g/100 seeds)	0.45	0.80**	0.35
Yield (kg/ha)	0.51	0.23	0.51

**Significant at 1% probability level.

Table 6. Analysis of variance for agronomic characters in F_1, F_2, F_3, and F_4 generations of 15 soybean genotypes grown in 1975 to 1981

Generations	Plant height	Flower-ing	Matu-rity	Height of lower pods	Branches/ main stem	Pods/ plant	Seeds/ plant	Nodes/ stem	Pods/ node	Seeds/ pod	Abort-ed seed	Seed size	Seed weight/ plant	Yield
F_1	**	**	**	**	**	**	**	**	**	**	**	**	**	**
F_2	--	**	**	--	--	--	--	--	--	--	--	**	--	**
F_3	**	**	**	**	NS	NS	**	*	*	**	**	**	**	**
F_4	**	**	**	**	**	*	*	**	NS	**	*	**	**	**

*Significant at 5% probability level.
**Significant at 1% probability level.
NS = Non-significant

Table 7. Combining ability analysis of agronomic characters of F_1 generations of soybeans (1975)

Sources of variation	DF	Plant height	Days to flower-ing	Days to matu-rity	Height of lower pods	Branches/ main stem	Pods/ plant	Seeds/ plant	Nodes/ plant	Pods/ node	Seeds/ pod	Abort-ed seed (%)	Seed size	Seed wt./ plant	Yield (kg/ha)
General combining ability	4	365.15**	233.54**	338.62**	69.91**	14.64**	5369.24**	18071.31**	25.78**	11.37**	0.37**	90.04**	4.89**	302.62**	319,284.28**
Specific combining ability	10	60.86**	4.01**	15.94**	3.24	2.44**	1411.75	6413.62**	5.70**	1.62**	0.02**	22.60**	0.40	88.74**	91,354.04**
Error	28	7.12	0.19	0.77	2.74	0.25	649.98	916.35	0.47	0.41	0.01	2.24	0.24	1.85	20,370.00
Gca MS/Sca MS		6.00	63.16	21.24	21.58	6.01	3.80	2.82	4.52	7.01	16.17	3.98	12.30	3.41	26.18
$\Sigma a^2 = \Sigma 2g^2$		86.93	71.29	92.19	19.05	3.49	1130.71	3330.77	5.74	2.79	0.10	19.27	1.28	61.11	65,122.92
$\Sigma d^2 = \Sigma s^2$		53.74	3.82	15.17	0.50	2.19	761.77	5497.28	5.23	1.21	0.02	20.36	0.16	86.89	70,984.04
$\Sigma a^2/(\Sigma a^2 + \Sigma d^2)$		0.62	0.95	0.86	0.98	0.61	0.60	0.38	0.52	0.70	0.85	0.49	0.89	0.41	3.59
$h^2\beta$		0.95	1.00	0.99	0.88	0.27	0.74	0.91	0.96	0.91	0.96	0.95	0.96	0.94	6.53
h^2N		0.59	0.95	0.85	0.86	0.59	0.45	0.34	0.59	0.63	0.81	0.46	0.76	0.41	3.12

** Significant at 1% probability level.

characters, we find that maturity, plant height, and seed size have high values that do not change much with successive generations. Yield has a very low value, and showed an increase from 42% with F_1 to 81% with F_4.

The gca and sca effects are given in Table 8. For yield, Nanjing 1138-2 had the highest gca value with 80.7, Nanjing 493-1 was next with 27.1, and Beeson the lowest with -128.4. The results were similar to those given for discriminating the combining ability of the parents (Table 3).

Crosses of U.S. cultivars produced hybrids inferior to crosses between U.S. and PRC cultivars. Nanjing 1138-2 had the lowest

Table 8. Gca effects and sca effects for agronomic characters in the F_1 generation of soybean crosses

		Parent				
Parent	Characters	Beeson	Xu-Zhou 424	SRF 400	Nanjing 1138-2	Nanjing 493-1
Beeson	Yield (kg/ha)	-963.38	203.78	-524.63	-119.25	133.88
	Seed weight/plant	-10.83	1.70	-5.76	-0.03	0.94
	Pods/plant	-43.78	8.84	22.71	10.40	-6.26
	Seeds/plant	-88.17	5.39	-47.10	23.57	-3.44
	Seed size	-0.45	-2.15	-3.06	-3.13	-1.82
	Days to flowering	-7.02	1.44	0.47	2.03	0.26
	Aborted seeds (%)	4.79	3.08	-1.61	-2.41	-3.26
	Plant height (cm)	-11.56	0.61	-5.53	4.75	3.44
Xu-Zhou 424	Yield (kg/ha)		174.78	116.55	800.40	294.75
	Seed weight/plant		2.29	0.95	8.34	6.66
	Pods/plant		-1.85	-4.49	19.57	28.41
	Seeds/plant		20.47	4.26	49.28	82.58
	Seed size		0.17	0.60	0.32	0.44
	Days to flowering		0.72	1.73	2.17	-1.80
	Aborted seeds (%)		-2.70	-2.22	-1.12	-7.88
	Plant height (cm)		6.20	7.01	8.70	3.98
SFR 400	Yield (kg/ha)			-24.45	1,005.53	136.65
	Seed weight/plant			-0.60	11.26	15.44
	Pods/plant			-1.91	35.87	72.27
	Seeds/plant			2.53	82.09	138.55
	Seed size			-0.82	0.51	0.42
	Days to flowering			-5.31	-0.45	0.73
	Aborted seeds (%)			2.57	-0.71	-4.66
	Plant height (cm)			-1.66	10.55	2.84
Nanjing 1138-2	Yield (kg/ha)				605.10	-272.55
	Seed weight/plant				6.60	-3.58
	Pods/plant				21.09	-14.83
	Seeds/plant				33.47	-35.91
	Seed size				1.35	0.35
	Days to flowering				4.89	0.53
	Aborted seeds (%)				-3.61	0.24
	Plant height (cm)				5.65	-6.48
Nanjing 493-1	Yield (kg/ha)					202.95
	Seed weight/plant					2.54
	Pods/plant					26.45
	Seeds/plant					31.71
	Seed size					-0.26
	Days to flowering					6.72
	Aborted seeds (%)					-1.06
	Plant height (cm)					1.37

sca effect. The gca and sca for the later generations of Nanjing 1138-2 showed a similar trend and are not given here.

The combined analysis for combining ability data is given in Table 9. We found that the MS for the genotype x generation interaction was highly significant, indicating that genotypes will not show similar behavior in different generations (F = 19.25). Thus the genetic variability of early generations may not be similar to that of later generations, and the early testing scheme in plant breeding for yield may not be as efficient as we expected. The combined analysis showed significant interactions of gca x generation and sca x generation. These two interactions were significant (F = 183.72 for gca and F = 4.22 for sca). These results indicate that the gca and sca of the parents will be different in different generations.

DISCUSSION AND CONCLUSION

The study of heterosis is very important for increasing soybean yield. Generally we ask the following questions: (1) Does the soybean hybrid exhibit hp heterosis and how large is the heterosis? (2) What are the component characters responsible for the yield heterosis? (3) Can we use seeds of advanced generations for commercial production?

In our experiments, we found that hp% for seed weight per plant averaged 20.9, and for yield averaged 17.2. F_1 heterosis was significant and justifies the production of commercial hybrid cultivars of soybeans.

The heterosis response of different agronomic characters varied with the different crosses. Heterosis for yield was determined by pods per plant, seeds per plant, and nodes per main stem, but not by seed size. Therefore, in selecting parents for making crosses, these three yield components should be considered.

Yield and yield components had significant inbreeding depression. For example, hp% for yield in F_1 was 17.2, in F_2 -16.5, in F_3 -8.9, and F_4 -14.3. From this, it is clear that only F_1 seeds should be used for commercial production.

Yield comparisons based on origin of parents showed that the crosses from distantly related origins have greater heterotic response than crosses from closely related origins.

F_1 is significantly correlated with F_2, F_3, and also F_4 for flowering and maturity, but F_1 is not significantly correlated with later generations for yield and its component characters.

The usefulness of the study of combining ability is threefold: first, by means of selecting parents with high combining ability, we make better crosses at the beginning; second, the relative importance of gca and sca of the parents can be used for predicting characters for early generation selection; third, F_1 heterosis and information on combining ability can provide information on gene action.

Our experiments included four generations. The analysis of F_1 data for combining ability showed significant gca for all agronomic characters. Most characters, especially yield, also had significant sca, indicating that nonadditive gene action was present. The ratios of gca to sca for all characters were large, indicating the greater importance of additive than nonadditive action. We obtained similar results when successive generations were analyzed.

For gca effect, Nanjing 1138-2 and Nanjing 493-1 were the best cultivars. For sca effects, the crosses using Nanjing 1138-2, Xu Zhou 424, and SRF 400 were the highest. These results may be used as a reference for selecting better parents in making crosses.

Yield had a low heritability of 42% in F_1, but it increased to 81% in F_4.

Table 9. Combined analysis of variance and combining ability of four generations for yield of soybean crosses

Sources of variation	DF	MS	Sources of variation	DF	MS
Genotypes	14	56847.1**	Generations	3	1005608.9**
Generations	3	73991.7**	Gca	4	103641.9**
Blocks	11	21099.6**	Gen x Gca	12	52976.3**
Gen x Genotype	42	22201.0**	Sca	10	16151.0**
Error	109	1153.4	Gen x Sca	30	1218.1**
			Error	109	288.4

**Significant at the 1% probability level.

Flowering, maturity, plant height, seed size, and seeds per node had rather high values in F_1, and did not change much in later generations.

From the combined analysis for yield, genotypes and generations of selfing were significant. The interactions between generations and gca and between generations and sca were significant, indicating that genotypes and their combining ability will change during selfing. Therefore for soybean yield, the performance of early generations cannot be used to predict later generations.

CONCLUDING DISCUSSION TO THE GERMPLASM, BREEDING, AND GENETICS WORKING GROUP SESSION

H. H. Hadley asked about the status of qualitative genetics in China.

Ma Rhu-hwa responded that most economic characters are quantitative characters so they get most of the attention.

R. L. Bernard asked about the distribution of some qualitative characters between north and south China.

Ma Rhu-hwa responded that in the north the cultivars have mostly light hilum colors and are indeterminate whereas in the south they have mostly dark hilums and are determinate.

H. Hadley asked if the inheritance of disease resistance was being studied.

Ma Rhu-hwa replied that the inheritance of resistance to soybean mosaic virus was now being studied.

C. D. Nickell asked if the genetics of the resistance to insects was being studied.

Wang Jin-ling said that they first study the significance of the use of the resistance and later will study the inheritance.

R. Palmer asked if mutant strains were being preserved.

Wang Jin-ling said that some were but not many. Ma Rhu-hwa said none were maintained at Nanjing.

H. H. Hadley asked how the yields of the hybrids Ma Rhu-hwa tested compared with the best currently grown cultivars.

Ma Rhu-hwa responded that the hybrids were compared with only the mid-parent and high-parent values because the parents which were used included high-yielding cultivars.

Wang Jin-ling asked if there would be hybrid soybeans in the U.S. soon. The consensus was that development would not occur soon.

Ma Rhu-hwa commented that much work remains to be done to make hybrid soybean cultivars possible.

Processing and Utilization Working Group Session

Convener: Earl D. Kellogg
Reporter: Ricardo Villota

Utilization of Soybeans in the Western Hemisphere

DALE W. JOHNSON

Harvested soybeans can be stored on the farm or shipped to country elevators, terminal elevators, or mill elevators. Beans with a moisture content greater than 13% can be stored for only a short time. Preferably, moisture content should be below 12% for long-term storage. During storage, the beans should be monitored to see that heating is not taking place. While in storage, beans should not be subject to weather conditions or possible contamination by rodents, birds, and insects.

At the mill elevator, beans are analyzed for foreign material, split beans, possible heat damage, moisture, oil, protein, and possible free fatty acids. The beans are graded according to these analyses. Before storage at the mill, the beans may be cleaned to remove sticks, stones, weed seeds, and other foreign material, and then dried.

In the preparation area in a processing plant the beans are cleaned, cracked, conditioned, and flaked. This phase of the operation is referred to as "preparation" (Fig. 1). The processing methods for beans will vary depending on ultimate use. The cleaning process of beans for lower protein/high fiber meal is not as exacting as that for producing high-protein meal. It is recommended that sound, whole, clean soybeans be used in the production of edible products.

After cleaning and conditioning, the beans pass through cracking rolls, followed by aspiration and screening to remove the major portion of the hulls. A variety of equipment and flow patterns may be used for the cleaning, cracking, dehulling, and flaking operations. For solvent extraction, the dehulled beans are conditioned before flaking. The flakes are then subjected to solvent extraction and desolventizing (Fig. 2). The oil is dissolved in the solvent, and the desolventized flakes will generally have a fat content well under 1%. The desolventizing of the solvent wet flake may be carried out using different processes, depending on whether the flakes are to be used for human food or animal feed. For animal feed the solvent wet flakes generally pass through a desolventizer toaster system in which live steam is used to evaporate the solvent and heat the soy flakes to inactivate undesirable enzymes and improve the nutritional value of the protein.

For soy flakes that will be used in edible products or to manufacture isolated soy proteins or soy protein concentrates, the desolventizing process and equipment use minimal heat in order to preserve the water dispersible protein. Flakes with a protein dispersibility index (PDI) from 35% to 90% can be produced using heated vapor desolventizing systems. In the case of flakes desolventized for animal feed, the PDI may vary from 15% to 35% and still destroy enzymes or antienzymes which are undesirable in feed

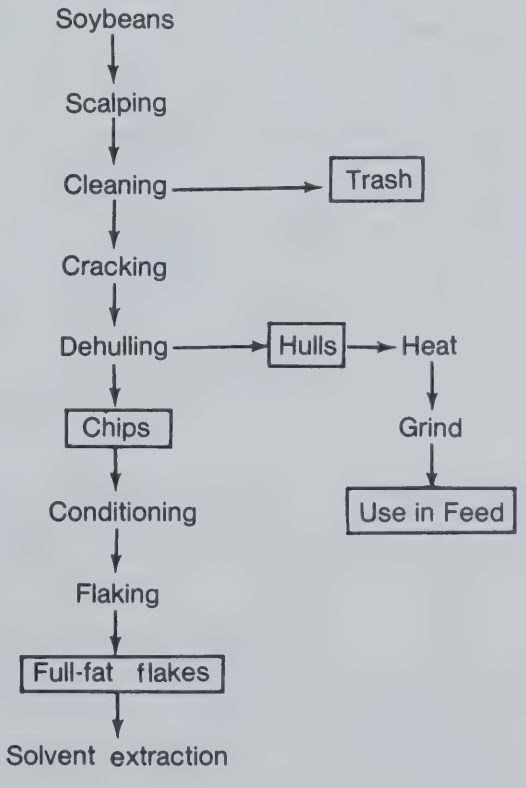


Figure 1. Steps involved in soybean preparation and processing.

D. W. Johnson is with Food Ingredients Minnesota, Inc., Golden Valley, Minnesota.

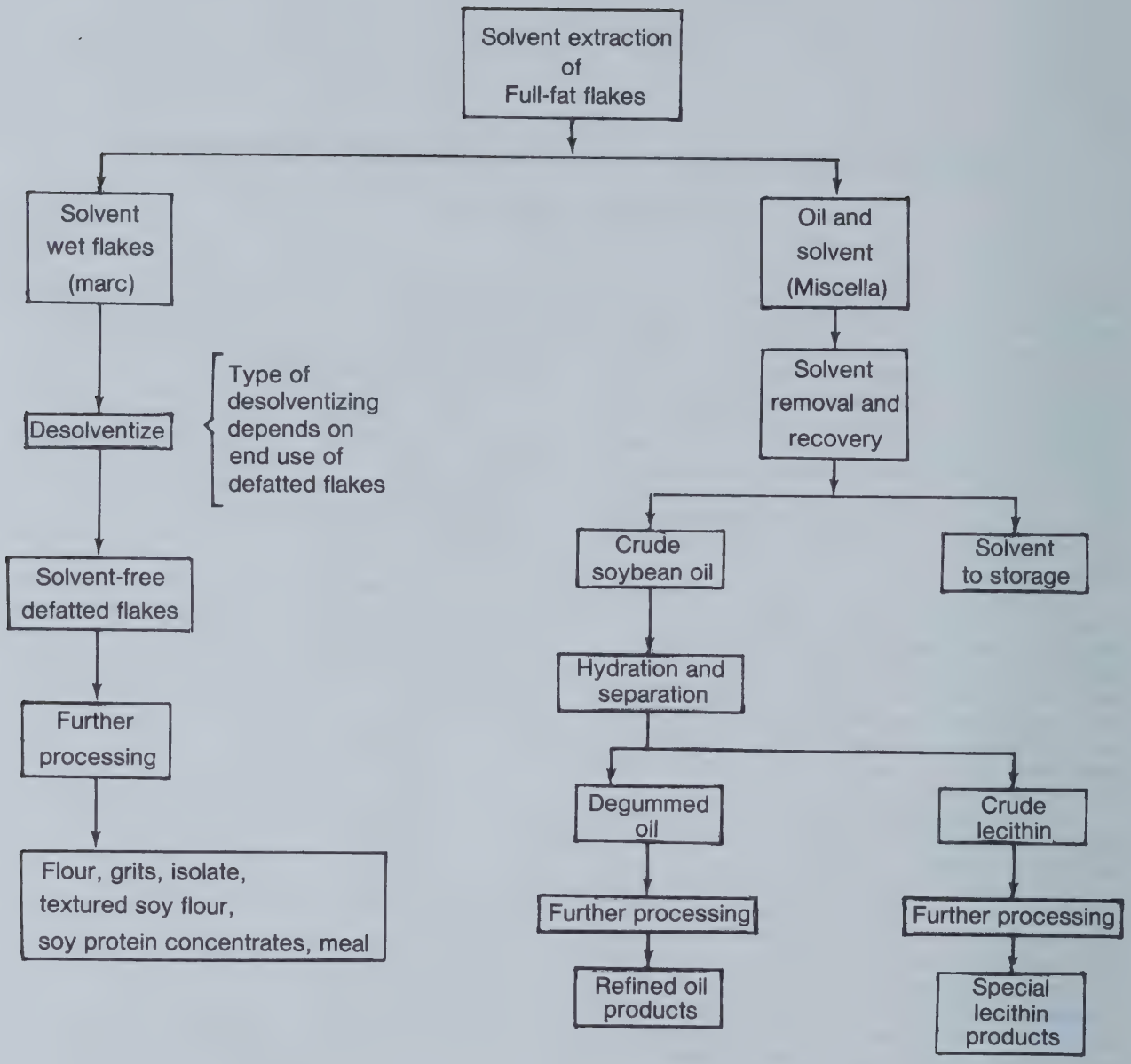


Figure 2. Products and steps in solvent extraction and product recovery of soybean full-fat flakes.

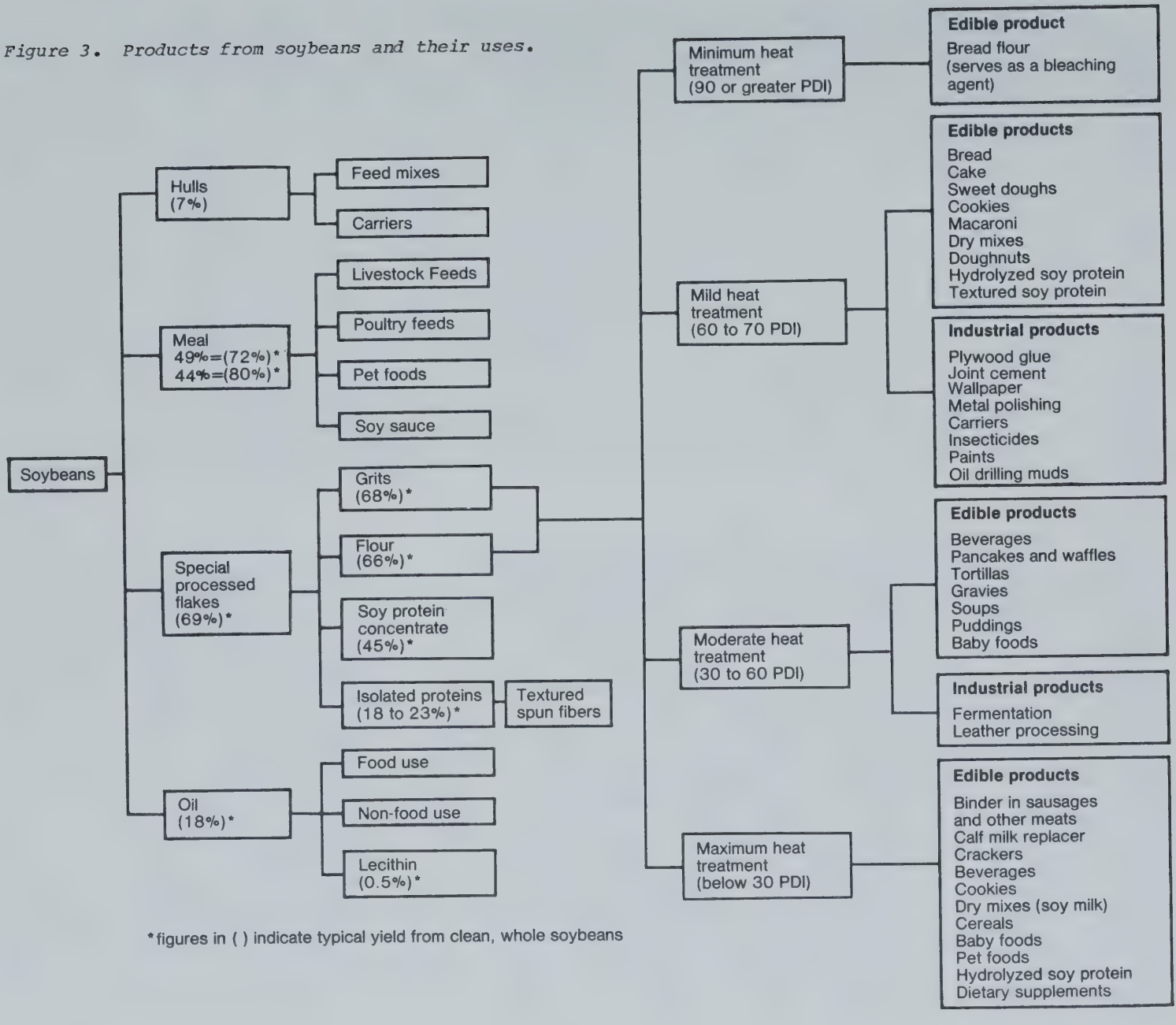
products. The heat-processed desolventized flakes are ground to break up lumps and screened to have a more uniform particle size for blending into other ingredients used in feed.

Besides soybean meal for livestock, other commercial products include soy flour and grits, soy protein concentrates, isolated soy protein, textured soy flour, textured soy protein concentrates, textured isolated soy protein, and soy beverages.

Figure 3 lists products from defatted soy flakes and a variety of food and industrial products in which the different types of soy materials are used. Soy products are added to food products in the West for their functional characteristics, with the nutritional value (with some notable exceptions) being more or less incidental.

The term "soy flour and grits" actually represents a number of different products having different physical and functional characteristics, depending on the degree of heat treatment and particle size. The type of soy flour or grits used will depend on the formulations or the process being used to produce the finished food product. In some cases there may be a choice of products

Figure 3. Products from soybeans and their uses.



*figures in ( ) indicate typical yield from clean, whole soybeans

which may be used. There are many reasons for choosing a particular type of soy flour and grits. In the case of soy proteins, a number of different products are available with different physical characteristics. There is a limited use of soy flour products in a number of industrial processes. Certain types of isolated soy proteins are used primarily as adhesives in paper coating, joint cements, and some other minor uses. A significant amount of soy flour and soy protein concentrate is used in milk replacers for feeding calves. Soy flour and grits, and more limited amounts of soy protein concentrate and soy protein isolates, are used in pet foods. There is no general reporting to government or other agencies on the production of soy products, so it is difficult to be accurate on the production of these items. However, there is no question that in the U.S. the combined production of soy flour and grits, soy isolates, soy protein concentrates, and textured soy protein products used for human and certain speciality animal feeds is probably in the range of one million metric tons per year.

At least 90% of the soybean oil which is produced in the U.S. is used for edible purposes in the form of salad oils, margarine, mayonnaise, and hydrogenated shortenings. A significant amount of the various soy products produced in the U.S. are exported to other areas of the world. Some soybean processors recover the lecithin and process it further into a number of specialty lecithin products.

Soy beverage products and soy tofu are gaining commercial interest in the U.S.

DISCUSSION

A. J. Seidler said it is important to consider the socio-economic aspects involved in the utilization of soy. In the past soy has been considered a "poor-man's food" in the U.S.

D. W. Johnson added that soy products are beginning to be accepted by the consumer. The use of soy has been approached from the economic viewpoint.

Sun Huan wanted to know why the consumption of soybean oil in the U.S. is so low. In the supermarkets corn and other vegetable oils are more readily available.

D. W. Johnson said that the main component of vegetable oils is soybean oil.

Sun Huan asked if the American consumer likes soybean oil. If so, why is it that vegetable oils are never labeled "soybean oil"?

D. W. Johnson said that soybean oil has been popularly accepted.

J. W. Erdman said that one of the reasons for labeling vegetable oils as such is that it gives the manufacturer the freedom to choose any vegetable oil that would keep the final product at a competitive cost. The composition of the oil is specified on the label.

Wang Jin-ling asked about the use of soy oil in margarine.

D. W. Johnson said that 95% of margarine comes from soybean oil. Concerning the acceptance of margarine, for example, most restaurants do not use it.

L. D. Williams added that in the U.S., approximately 70% of the vegetable oil available is soybean oil. An interesting issue is that very few housewives would say that they consume soybean oil. Soybean oil, however, is considered to be cheap and better from a nutritional point of view.

D. W. Johnson said that in Japan, as in many other countries, soybean oil is consumed in greater quantities than other oils.

L. S. Williams said that sunflower oil would be the second most important type of vegetable oil, primarily because of the U.S.S.R. production.

Guo Xiang-ao asked about the production of soybean products in the U.S.

D. W. Johnson replied that a rough summary of U.S. annual soy products production would be:

soyflour and grits	600 million kg
soy protein concentrate	55 million kg
soy protein isolate	55 million kg
textured soy flour	70 million kg

Guo Xiang-ao asked about spun soybean protein production.

D. W. Johnson said that the production of spun soybean protein in the U.S. is negligible.

Utilizing Soybeans with Field, Frost, and Freeze Damage

A.J. SIEDLER

Field damage can happen anywhere soybeans are grown. When the soyben crop has matured and the seeds are dry enough for harvest, they often are subjected to repeated damp weather. Under such conditions seeds take up moisture, which encourages rapid mold growth, and they become a dark-colored moldy mass. Frost damage and freeze damage are more likely to occur in northern soybean producing areas. When growth of the plant is arrested by temperatures of -6°C or lower, freeze damage occurs. This kills leaves, stems, pods, and seeds. There is no continuing maturation in any part of the plant, and seeds (both seed coats and cotyledons) dry to a dark-green color. These seeds are smaller than undamaged seeds.

FREEZE OR FROST DAMAGE

The temperature at which freeze damage occurs has been carefully determined. Subjecting the entire plant to temperatures above -6°C did not consistently produce freeze-damage. However, temperatures of -6°C or lower resulted in typical freeze-damage.

When the temperature drops to -3°C, frost damage occurs. In frost damage, which is less severe than freeze damage, leaves are killed and some surface damage to pods and stems occurs. However, the seeds continue to mature and lose their green color except for a slight tinge of green in some seed coats.

The commercial value of frost-damaged soybeans may not be significantly altered. The official grain standards of the United States for soybeans state that yellow seeds may have green seed coats if the cross sections of 90 percent or more of the cotyledons contain a yellow tinge. In other words, soybeans with only a modest amount of green color are classified as yellow. Severely damaged seeds will be classified as green. They must have both green seed coats and be green in cross section. Often a field will have both frost- and freeze-damaged soybeans. In this case, seeds from the field could not be classified yellow or green and would be classified as mixed.

Freeze- or Frost-damaged Soybeans for Oil Crushing

Oil removed from soybean seeds must be refined for human consumption. During refining, impurities such as free fatty acids and colored materials are removed. To the oil processor, the larger the amount of free fatty acids and colored materials, the lower the yield of salable oils. Freeze-damaged seeds have a significantly higher amount of free fatty acids than undamaged ones at the harvest and therefore are of less value to the oil processor (Table 1). Freeze-damaged soybeans also will have a higher rate of increase in free fatty acids during storage than undamaged beans (Fig. 1).

Therefore, freeze-damaged beans should be processed as quickly as possible.

Freeze- or Frost-damaged Soybeans for Whole Bean Human Foods

The U.S. soybean crop is used primarily for oil and meal. However, in some countries,

Table 1. Free fatty acid in oils from freeze-damaged, field-damaged, and undamaged soybeans

Source of oil	Free fatty acid (%)
Williams	
Field-damaged	0.19
Freeze-damaged	0.28
Undamaged	0.15
Clark 63	
Field-damaged	0.23
Freeze-damaged	0.24
Undamaged	0.12

A. J. Siedler is head, Department of Food Science, UIUC.

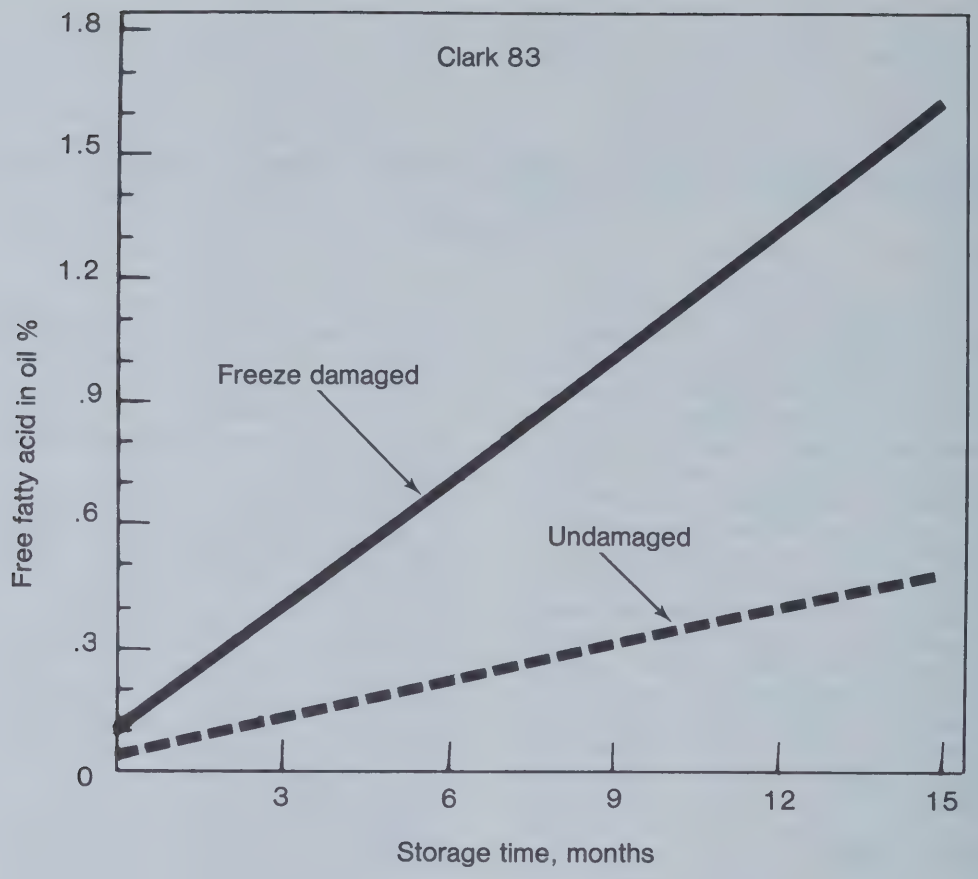


Figure 1. Free fatty acid in oils from soybeans subject to storage.

the use of whole soybeans for human consumption is important and increasing.

University of Illinois at Urbana-Champaign researchers have developed various ways to formulate foods from whole soybeans, including a soybean beverage. Sensory evaluations were made on these various foods to study the effect of freeze damage on the quality of the food prepared from these beans. The flavor and color acceptance of freeze-damaged soybeans always was rated lower than that of undamaged ones (Table 2). The use of frost-damaged or mildly freeze-damaged beans for beverages and other whole bean foods would significantly reduce acceptability because of poor color and off-flavors. Therefore, separate color and other quality standards are needed for selecting soybeans for whole soybean foods.

FIELD DAMAGE

Moldy or weather-damaged seeds contribute to the damaged seed count for grade consideration. A damage level of 2% classifies a shipment as U.S. No. 2 grade; 3% classifies it as U.S. No. 3; 5% or more, U.S. No. 4; and if the damage level is greater than 8%, a sample grade is given.

Table 2. Sensory evaluations of cooked freeze-damaged and undamaged soybeans

Source	Mean sensory scores[a]		
	Color	Flavor	Off-flavor
Nonstored			
Freeze-damaged	3.8	5.7	4.6
Undamaged	7.9	7.2	7.2
Stored 6 months			
Freeze-damaged	2.9	3.9	3.2
Undamaged	8.6	6.9	6.5

[a] 1 = highly unacceptable, 5 = acceptable, 9 = excellent.

Field-damaged Soybeans for Oil Crushing

Like freeze-damaged beans, field-damaged beans have high levels of fatty acids and are red instead of green.

The material remaining after oil extraction (soybean meal) primarily is used in animal feed, with only about 3% used for human food. Studies with swine show little difference in meal from field-damaged soybeans compared with meal from undamaged beans. The consumption of these meals by swine was identical, and the protein quality and energy levels were essentially the same (Fairbanks et al., 1947). If the percentage of field-damaged soybeans is high, it is likely that the meal will no longer be acceptable for feed. Further research is needed to establish the maximum acceptable level and to determine if there may be problems with mycotoxins that might be produced by molds.

Field-damaged Soybeans for Whole Bean Human Foods

This is one area where many questions remain unanswered. Soybeans are not recommended for human food until tested for mycotoxins if there is a trace of field damage. If the overall damage to a lot of soybeans is not great, it might be possible to separate the damaged from the undamaged seeds with electronic sorting devices. Whether this would be economically feasible at the present time is doubtful. Another problem is that some mold damage is not very apparent.

CONCLUSIONS

Frost, freeze, and field damage causes higher levels of free fatty acids and color impurities in soybean seeds, lowering their quality and making refining more difficult and costly.

If slight frost damage occurs, the damage may not be reflected in a lower U.S. Department of Agriculture grade. Freeze-damaged and some frost-damaged seeds rank poorly in flavor, off-flavor, and color, and are undesirable for human food, but appear to be safe for human consumption. More definitive work on freeze or frost damage is needed to determine processing tolerances for damaged soybeans.

Field damage from mold can make the beans unsafe for human or animal use. Until this area is further researched, it is not possible to make definitive statements about acceptable (and unacceptable) levels of field damage.

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DISCUSSION

L.S. Wei stated that the UIUC project on frost-damaged soybeans was started as a consequence of an early winter in Illinois. Researchers were interested in studying the potential damages inflicted by frost and freezing upon the quality of soybeans. Freeze damage was simulated by spraying the crop with a herbicide, and the crop was then machine-harvested to obtain larger samples for analysis. One interesting observation was that the concentration of phytates was lower in immature beans. Unfortunately, the quality of the immature beans as food was not satisfactory. Researchers are at present interested in checking on the following characteristics, before and after storage: 11S and 7S protein ratio; emulsifying capacity; water absorption; gelation.

L. D. Williams asked if possible changes in trace metals due to the frost have been examined. L. S. Wei said no.

H. E. Kauffman asked if there were problems associated with frost damage in China.

Wang Jin-ling replied that in northern China the growing season is short, and early frost would cause damage to the soybeans. However, the degree of damage and the quality of the damaged soybeans have not been studied. Immature soybeans are rejected by manufacturers.

E. D. Kellogg said that frost damage to soybean crops is a problem common to China and the U.S. and that the possibility of a joint program between the two countries to further study this area should be considered.

Application of Membrane Processing in the Soy Protein Industry

MUNIR CHERYAN

Membrane separation processes are based on osmosis, which is the ability of semipermeable membranes to discriminate between molecules on the basis of molecular size, shape, and, to a lesser extent, chemical composition. Osmosis was demonstrated in 1748, but it was early in the 1960's when synthetic anisotropic membranes were developed that produced reasonably high flux (dewatering rates) and could withstand high pressures.

Commonly used processes are reverse osmosis (RO) and ultrafiltration (UF). For both RO and UF, feed solution is pumped under pressure over the surface of the membrane. In RO, the membrane rejects all components of a solution except water. Consequently, osmotic operating pressures of 34 to 102 kg/cm are common. In effect, RO is essentially a dewatering technique.

Besides being a dewatering technique, UF also is a fractionation, purification, and macromolecule concentration method. The membrane retains materials with large molecular weights, while solutes with low molecular weights pass through. Pressures for UF are lower than for RO. Permeability and selectivity characteristics of membranes can be controlled during its manufacture by varying the pore size or "molecular weight cut-offs." Ultrafiltration and RO are the first continuous molecular separation processes that do not involve a change of phase or state of the solvent or interphase mass transfer. These implications interest food processors (Cheryan, 1978).

SOYBEAN APPLICATIONS

The relatively high quantity and quality of protein and fat make soybeans a valuable raw material for the manufacture of protein isolates and other products that can be used in the formulation of a variety of nutritious foods. For optimum soybean utilization, certain off-flavor factors and anti-nutritional compounds must be reduced or eliminated. Proper heat treatment has proven effective in reducing lipoxygenase-induced off-flavors and trypsin inhibitors; however, it is of little value in controlling other factors such as oligosaccharides or phytic acid. Isoelectric precipitation methods reduce oligosaccharide content to negligible levels, but have little effect on phytic acid content, result in low protein yields, and may impair functional properties of the product (Cheryan, 1980).

Ultrafiltration has been investigated as a means of overcoming many of these problems. The desirable components of soybeans --protein and fat--are relatively large in terms of molecular size, while the undesirable components--phytic acid and oligosaccharides--are small. By careful selection of membrane characteristics and operating parameters, one can selectively remove the undesirable components. Since no heat or chemical treatment is required, the product should be low in energy consumption. In addition, whey proteins normally lost in conventional processes now are retained in the product, thus further improving functional properties.

A schematic diagram for the process developed at the University of Illinois at Urbana-Champaign for production of full-fat soybean protein concentrates from whole soybeans is shown in Figure 1 (Omosaiye et al., 1978; Omosaiye and Cheryan, 1979a; Omosaiye and Cheryan, 1979b). Blanching is necessary for the prevention of lipoxygenase-induced off-flavors; the conditions used (3 minutes at 90°C) had relatively little effect on protein solubility. The prefiltration step was designed to remove coarse insoluble particles greater than 100 μm. Essentially all insoluble carbohydrate and fiber was removed as the filter cake, as well as smaller quantities of protein, fat, ash, and soluble carbohydrate. The extract then was subjected to UF using hollow fiber module with a 50,000 molecular weight cut-off membrane.

M. Cheryan is associate professor of food engineering, UIUC.

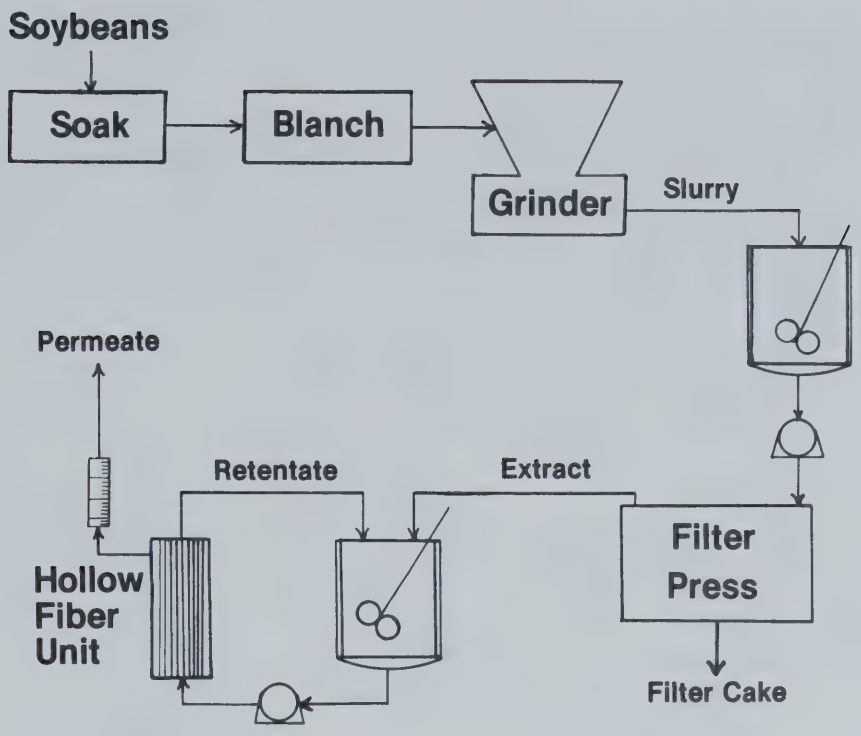

Figure 1. Production of full-fat soybean protein concentrate or purified "soymilk" from whole soybeans by ultrafiltration. [Reprinted from Journal of Food Science 43(2):354 (1982). Copyright© by Institute of Food Technologists. With permission].

The final product assayed 60% protein, 35% fat, 2.5% ash, and greatly reduced quantities of oligosaccharides, phytic acid, and active trypsin inhibitor as compared to the soybeans. Functional properties of this product have been studied and are superior to conventional products (Lah and Cheryan, 1980a; Lah and Cheryan, 1980b; Lah et al., 1980).

A schematic of a process for production of soy isolates by ultrafiltration is presented in Figure 2 (Nichols and Cheryan, 1981a). Yields of isolate (containing 90% protein, N x 6.25, dry basis) are typically 50% of the starting weight of the defatted soy flour.

A process diagram for production of protein blends from cheese whey and defatted soy flour by co-extraction and co-ultrafiltration is shown in Figure 3. This process was developed specifically to meet the growing demand in the U.S. for functional food ingredients that combine the versatility of dairy proteins with the economy of vegetable proteins. The major advantages are: (1) high-protein blends can be produced without prior isolation or concentration of whey or soy protein, (2) mild operating conditions with no phase change of solutes or solvents, (3) easy control of composition: the proportion of whey protein to soy protein is controlled during the co-extraction step, while the final protein content or degree of purification is controlled by the extent of co-ultrafiltration processing, and (4) an otherwise major pollution source (cheese whey) can be utilized. The process is described by Nichols and Cheryan (1982) and Cheryan and Nichols (1982).

The processing-engineering aspects of the ultrafiltration of soy systems also has been studied (Cheryan, 1977; Cheryan and Schlesser, 1978; Cheryan and Nichols, 1980; Nichols and Cheryan, 1981b).

PROTEIN HYDROLYZATES

Another potential application of membrane technology is in the development of continuous membrane bioreactors. We applied this concept to the continuous hydrolysis of oligosaccharides (Kohlwey and Cheryan, 1981) as well as to the production of "hydrolyzed vegetable proteins" or protein hydrolyzates. These are proteins that are broken down into peptides and amino acids to improve their functional properties and thus enhance their utilization. Enzymatic hydrolysis is preferable to acidic or alkaline hydrolysis; since the former process uses milder condi-

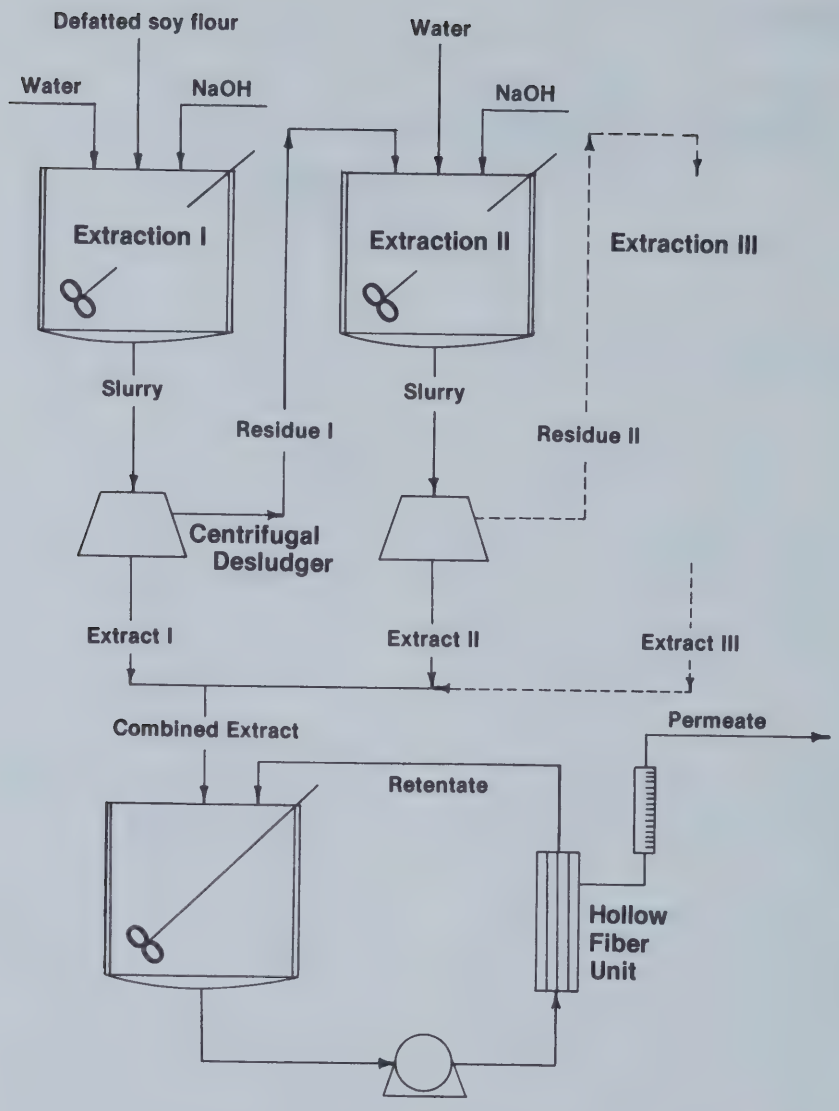

Figure 2. Production of soy isolates by ultrafiltration. [Reprinted from Journal of Food Science 46(2):357 (1981). Copyright© by Institute of Food Technologists. With permission]

tions, it results in fewer off-flavors, and the final product has a lower residual salt content. However, conventional batch enzyme hydrolysis methods have problems, such as the relatively high cost of the enzymes (which are inactivated at the end of the process), batch-to-batch variation in product thus making functional properties more difficult to control, and relatively low yields and productivity. Furthermore, if the reaction is not carefully controlled, it could lead to excessive bitterness and off-flavors (Cheryan and Deeslie, 1980a; Deeslie and Cheryan, 1979).

The UF reactor concept overcomes several of these drawbacks simultaneously (Fig. 4). The system is a classic continuous stirred tank reactor (CSTR) coupled in a semi-closed loop configuration to an ultrafiltration module. Steady state is reached rapidly, typically within 30 to 60 minutes. Several operating variables can be manipulated to optimize the system performance, such as enzyme concentration, substrate concentration, flow rate, reaction volume, pH, temperature, calcium concentration, etc. Details of its performance and operating characteristics have been published (Cheryan and Deeslie, 1980b; Cheryan and Deeslie, 1981; Cheryan and Deeslie, 1982; Deeslie and Cheryan, 1981a; Deeslie and Cheryan, 1981b; Deeslie and Cheryan, 1982).

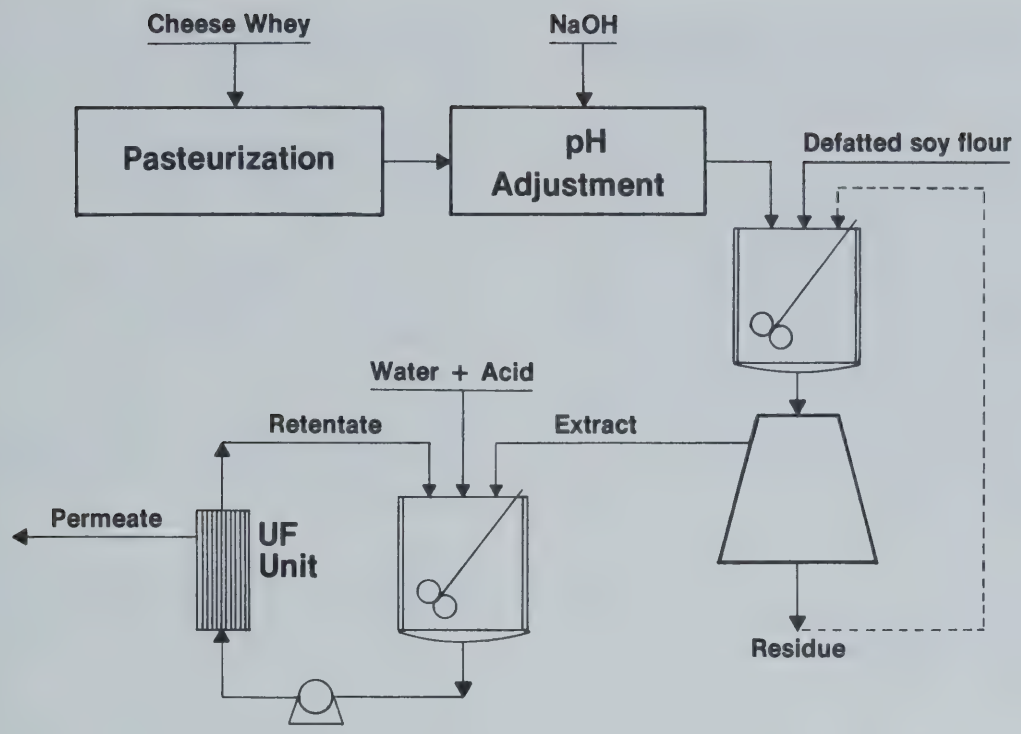

Figure 3. Process diagram for production of high protein blends from cheese whey and defatted soy flour by co-extraction and co-ultrafiltration. [Reprinted from Journal of Food Science 47(2):486 (1982). Copyright © by Institute of Food Technologists. With permission]

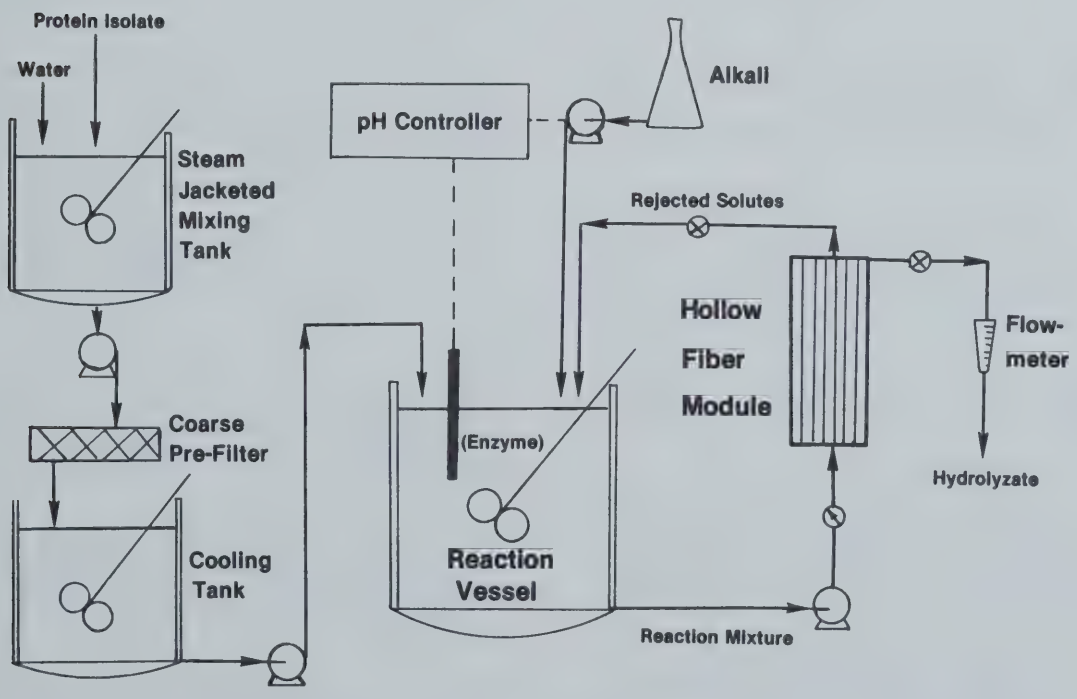

Figure 4. Process for continuous hydrolysis of proteins in a membrane (ultrafiltration) reactor. [Reprinted from Journal of Food Science 46(4): 1035 (1982). Copyright © by Institute of Food Technologists. With permission]

A UF reactor with a 10,000 molecular weight cut-off membrane, using soy isolate (Promine-D) and the enzyme Pronase, will, under optimum conditions, produce a hydrolyzate of 91-93% "protein" (N x 6.25) and 5-9% ash, on a dry basis. Yields in excess of 90% on a protein basis are possible, and productivity is typically 20 to 50 times greater than a conventional batch reactor, primarily due to recycling the enzyme. The product (hydrolyzate) is fairly bland, not bitter, clear, completely soluble over the pH range of interest in foods, an excellent water binder, and a potentially good antioxidant. This product should be of particular value in "medical diets," infant formulas, nutritional fortification of beverages, and intermediate moisture foods.

Studies are continuing here at the University of Illinois at Urbana-Champaign on membrane applications in the soybean industry. This new technology has several potentially important applications.

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DISCUSSION

Sun Huan asked what the conditions are for the production of protein hydrolyzates.

M. Cheryan said that the process of hydrolysis is carried out at pH 8 and 50°C.

A. J. Siedler asked what degree of hydrolysis is accomplished in this process.

M. Cheryan said that peptides as small as 2,500 molecular weight are obtained. The process is very efficient because the product is removed before any inhibition occurs.

A. J. Siedler stated that in this process it should be taken into consideration that the enzyme may hydrolyze itself.

M. Cheryan said that process conditions can be modified in order to avoid enzyme damage. For instance, using a process temperature of 37°C, less enzyme damage will occur, although microbial growth would be more likely to occur. At 50°C, better results are obtained; however, enzyme damage is more serious.

A. J. Siedler said he thought that pH can be modified or manipulated in the same fashion as temperature. He asked if any experiments at different pH values had been carried out. M. Cheryan said no.

Minimizing Protein Insolubilization during Thermal Inactivation of Lipoxygenase in Soybean Cotyledons

LUN SHIN WEI

Soybeans have been used in preparing various types of food in the Orient for many centuries. However, off-flavors described as painty or beany have limited the acceptability of these foods in other parts of the world. Using heat to inactivate lipoxygenase in soybeans greatly improved the flavor (Nelson et al., 1976; Wilkens et al., 1967; Mustakas et al., 1969). Unfortunately, protein insolubilization occurred with heat inactivation of lipoxygenase, limiting usefulness of the resulting product. Therefore this study was initiated.

Pre-moistened cotyledons were steam-heated for short times and then held for various times before cooling and analyzing.

EXPERIMENT

Seeds of Williams cultivar (certified) stored at 1°C were used for all experiments. The soybeans were dehulled to give intact cotyledons (Spata et al., 1974). Moisture content was adjusted by soaking the cotyledons for up to 12 minutes in soft water (3 grains hardness per gallon) or a carbonate alkaline buffer at pH 9.8 (0.115 M KOH and 0.250 M $NaHCO_3$) or pH 10.8 (0.164 M KOH and 0.186 M $NaHCO_3$). Equilibration of the moisture in the cotyledons was done at 1°C. The moisture content was determined by air oven drying and expressed on dry weight basis. Water activity was determined by a method developed by Lang et al. (1981).

Three-hundred grams of cotyledons, prepared with and without moisture adjustment, were heated for 9 to 12 seconds in atmospheric steam and transferred to an insulated, closed box placed in a constant-temperature air cabinet. The temperature of the atmosphere in equilibrium with the cotyledons was determined to be between 60° and 95°C as measured by a thermocouple in the geometric center of the insulated box. The air temperature of the cabinet was adjusted to that of the cotyledons to establish isothermal conditions in the box. The cotyledons were held in the insulated box for various times to 60 minutes and then cooled by immersion in ice water for 30 seconds. The cooled cotyledons were dried for eight hours at 40°C with high air flow and then for 60 hours at 25°C with minimal air flow. Finally, they were ground to 40 mesh by a laboratory hammer mill and moisture content of the ground samples determined.

The nitrogen solubility index of the ground sample was determined using Kjeldahl nitrogen analysis (Ayers, 1968). The pH of a 2% soy solids slurry in distilled water was determined after two hours of stirring. Samples were defatted by soxhlet extraction with petroleum ether (b.p. 30-60°C) in preparation for lipoxygenase activity determination. The lipoxygenase was extracted from the defatted samples by a procedure described by Klein (1976) modified by extracting with 0.05 M borate buffer for one hour at 1°C. The lipoxygenase activity was determined using the procedure of Rice et al. (1981). Controls were unheated cotyledons that had received the same preparatory soak as the heated cotyledons.

CALCULATIONS

Because we were treating soybean cotyledons rather than a powder or a liquid, a major difficulty in analyzing the effect of temperature was that no isothermal studies could be done, i.e., no individual cotyledon temperature could be duplicated. In order to circumvent this difficulty, we used the first-order rate equation and the Arrhenius equation to relate time and temperature of cotyledon treatment with either enzyme inactivation or protein insolubilization. Lipoxygenase inactivation and decrease in nitrogen solubility index (NSI) have been shown to follow a first-order rate of degradation (Wapinski, 1977).

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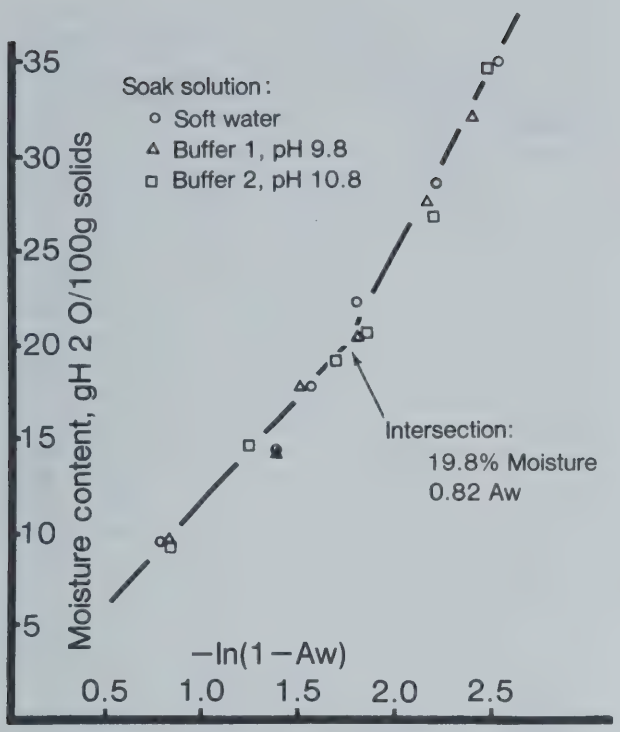

Figure 1. Water activity (Aw) at 20°C for cotyledons adjusted in moisture content by soaking in soft water or a carbonate buffer.

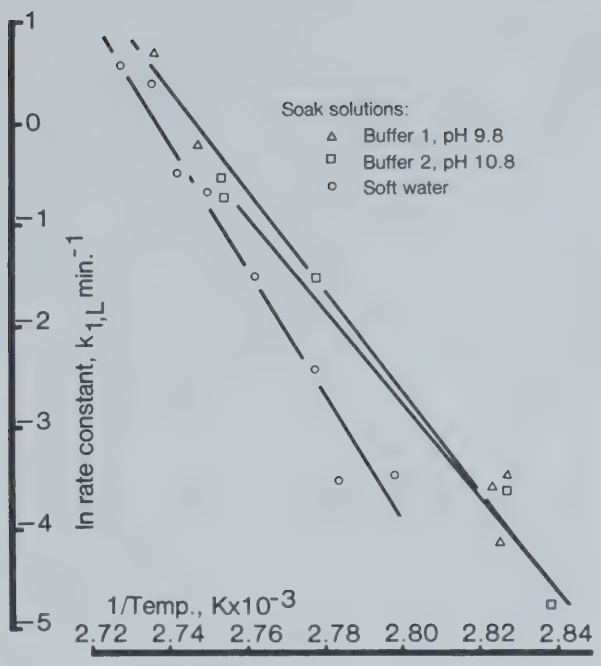

Figure 2. Arrhenius plots of rate constants for thermal inactivation of lipoxygenase in cotyledons adjusted to an initial moisture content of 16.3% by soaking in soft water or a carbonate buffer.

RESULTS AND DISCUSSION

Sorption Isotherm Data

The water activity of cotyledons adjusted to moisture contents of 9.7% to 35% in each of the three solutions was determined at 20°C. The data are presented as a Smith Plot (Smith, 1947) (Fig. 1). All the points fell on a common line, showing that soak solution had no effect. However, the breakpoint at 19.8% moisture and 0.82 Aw resulted in two straight lines with slopes statistically different (5% level). Lang and Steinberg (1981) showed that in a heterogeneous material, one state of water exists below the breakpoint as polymer water and an additional state of water exists above it as solute water. The lower line of the sorption isotherm is in agreement with the data for whole soybeans (Alam and Shove, 1972). Based on this result, two moisture contents were chosen for the enzyme inactivation studies: one below the break, 16.3%, and one above the break, 32.0%.

Heating at 16.3% Moisture

Cotyledons adjusted to 16.3% moisture in each of the three solutions were steam-blanched to a range of temperatures. Arrhenius plots of the rate constants for lipoxygenase inactivation indicate that adjusting the cotyledon moisture content to 16.3 $\pm$ 1.0% with either pH 9.8 or pH 10.8 buffer increased the rate of inactivation at a given temperature as compared with adjusting with soft water (Fig. 2). From the slopes of the lines for soft water, pH 9.8 buffer, and pH 10.8 buffer, activation energies for the inactivation rates were calculated to be 127.4 $\pm$ 9.4, 97.0 $\pm$ 4.7, and 103.3 $\pm$ 13.1 kcal/mol, respectively. The temperature dependence for the rates of lipoxygenase inactivation was decreased significantly (10% level) by the use of the buffers. There was no difference between the buffer solutions.

From the Arrhenius plots of the rate constants for protein insolubilization (Fig. 3) in soft water and pH 9.8 and pH 10.8 buffers, the activation energies were calcu-

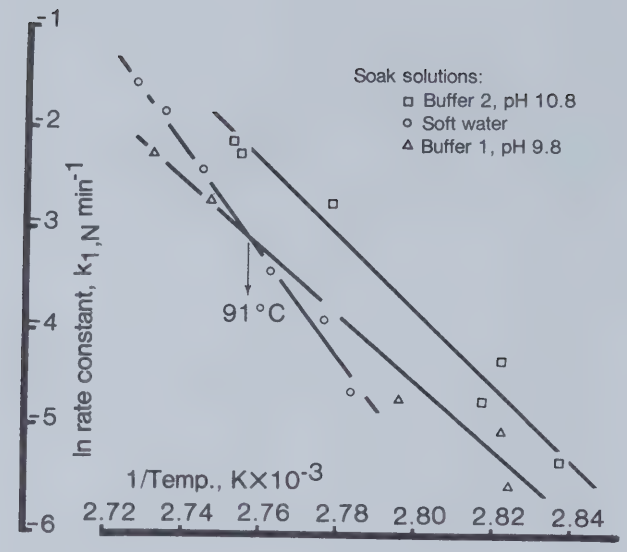

Figure 3. Arrhenius plots of rate constants for thermal insolubilization of protein in cotyledons adjusted to an initial moisture content of 16.3% by soaking in soft water or a carbonate buffer.

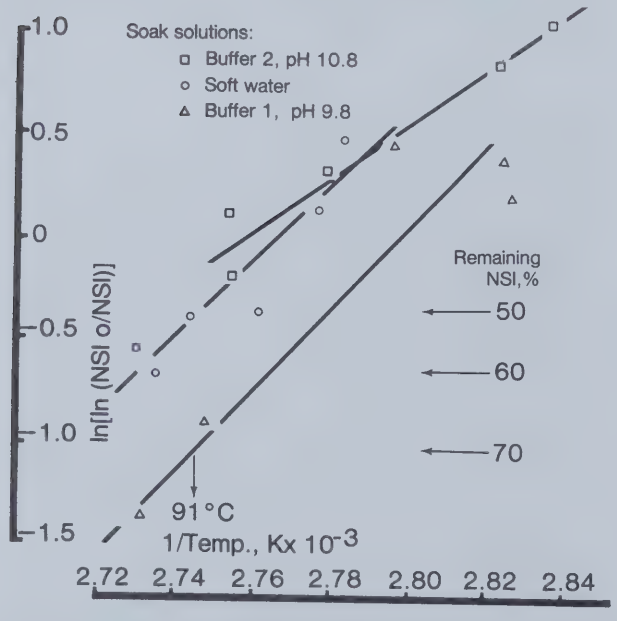

Figure 4. Arrhenius plots showing remaining soluble protein after a 99% reduction of lipoxygenase activity in cotyledons adjusted to an initial moisture content of 16.3% by soaking in soft water or a carbonate buffer.

lated to be 104.2 ± 5.9, 67.6 ± 5.9, and 71.8 ± 6.5 kcal/mol, respectively. The lines for soft water and the pH 9.8 buffer intersect at 91°C; at temperatures above this, the pH 9.8 buffer gave a relative decrease in the rate of protein insolubilization; and the pH 10.8 line paralleled the pH 9.8 line, indicating relatively higher insolubilization rates for a given temperature. Both buffers reduced temperature dependence of the insolubilization reaction as compared with soft water.

In order to relate the degree of protein insolubilization to enzyme inactivation under different conditions, the ratio of NSI after heating to 99% inactivation of lipoxygenase was calculated as a percent of NSI before heating. These values were plotted against the reciprocal of absolute temperature (Fig. 4). The use of the pH 9.8 buffer significantly increased the remaining soluble protein; above 91°C at least 70% of the soluble protein was retained, and the use of the pH 10.8 buffer gave no improvement over soft water. Borhan and Snyder (1979) found that, for the same amount of enzyme inactivation in whole soybeans soaked in 10% ethanol at 45°C, the addition of Na_2CO_3 to the soak solution resulted in a higher retention of soluble protein than equimolar amounts of NaOH. The pH 9.8 buffer contained more carbonate and less hydroxyl than the pH 10.8 buffer. Therefore, a higher carbonate concentration is more valuable here than a higher pH.

Adjustments with soft water to 16.3% moisture resulted in a maximum NSI retention of about 55-60% of the initial as a result of steaming and holding at 95°C (Fig. 4). This agrees with Wapinski (1977), who found a maximum NSI retention of around 60% after inactivation of lipoxygenase in cotyledons adjusted to 16.3% moisture with soft water by steaming alone. Thus, the holding period was of no advantage in the case of lower moisture.

Heating at 32.0% Moisture

Arrhenius plots of the rate constants for lipoxygenase inactivation in cotyledons adjusted to 32.0 ± 1.0% moisture indicated that the two carbonate buffers affected the inactivation rates differently (Fig. 5). The pH 9.8 buffer did not appreciably change the rate of lipoxygenase inactivation over the soft water control. In contrast, the pH 10.8 buffer caused a marked increase in the rate of inactivation at a given temperature. From the slopes of the lines for soft water, pH 9.8 buffer, and pH 10.8 buffer, the activation energies for the inactivation of lipoxygenase were calculated to be 104.6 ± 10.1, 107.4 ± 11.5, and 105.7 ± 5.5 kcal/mol, respectively. This shows the buffers did not alter the temperature dependence of the inactivation rate.

The effects of the buffers as compared with soft water on the rate of inactivation (Fig. 6) were different in two ways from

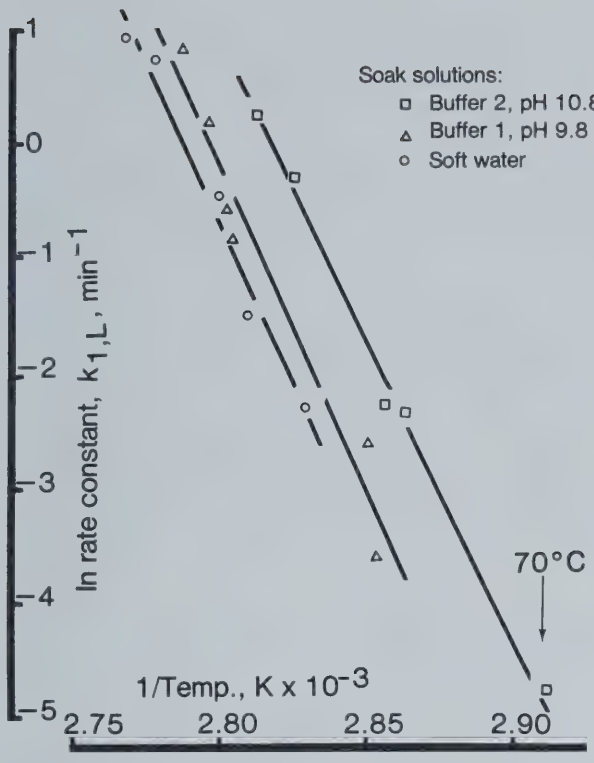

Figure 5. Arrhenius plots of rate constants for thermal inactivation of lipoxygenase in cotyledons adjusted to 32.0% moisture by soaking in soft water or a carbonate buffer.

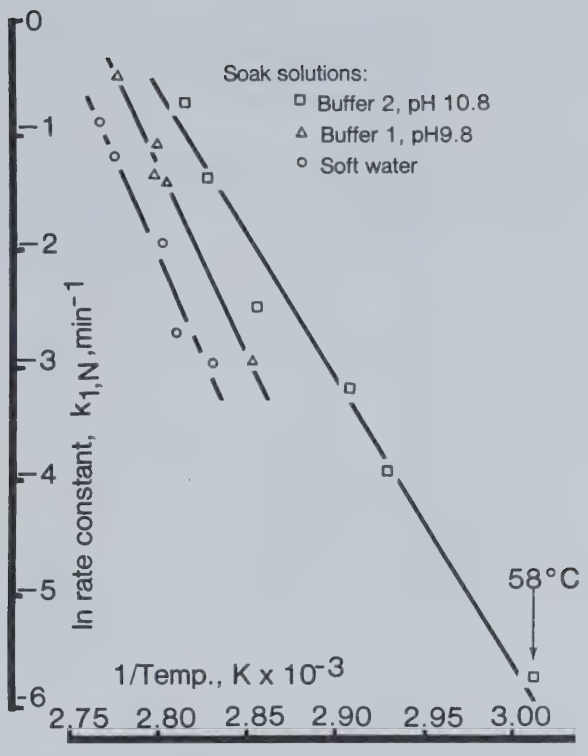

Figure 6. Arrhenius plots of rate constants for thermal insolubilization of protein in cotyledons adjusted to an initial moisture content of 32.0% by soaking in soft water carbonate buffer.

those at 16.3% moisture (Fig. 3). First, at 16.3% the use of either pH 9.8 or pH 10.8 buffer increased the rate of inactivation at lower temperatures, while at 32.0% moisture only the pH 10.8 buffer significantly increased the rate of inactivation. Second, at 16.3% moisture the use of either pH 9.8 or pH 10.8 buffer decreased the temperature dependence of the rate of inactivation, while at 32.0% neither buffer altered the temperature dependence of this rate.

Arrhenius plots for the rates of insolubilization of protein in cotyledons at 32.0% moisture indicated that the two carbonate buffers increased the protein insolubilization rates differently, compared with soft water, at a given temperature (Fig. 6). The pH 9.8 buffer increased the insolubilization rate over that observed for soft water; the pH 10.8 buffer increased the rate over that observed for the pH 9.8 buffer. From the slopes of the lines for soft water, pH 9.8 buffer, and pH 10.8 buffer, the activation energies for the insolubilization of protein were calculated to be 66.9 $\pm$ 8.1, 66.3 $\pm$ 5.8, and 46.7 $\pm$ 3.8 kcal/mol, respectively. From these activation values, it can be seen that the pH 10.8 buffer significantly decreased the temperature dependence while the pH 9.8 buffer did not as compared with soft water.

It is interesting to compare protein insolubilization in pH 9.8 buffer with that in soft water at 32.0% moisture (Fig. 6) and at 16.3% moisture (Fig. 3). There are two differences. First, at 16.3%, the insolubilization rate was decreased above 91°C as opposed to an overall increase in the rate at 32.0% moisture. Second, at 16.3% moisture, the temperature dependence for the pH 9.8 buffer in comparison with soft water was significantly decreased while it remained the same at 32.0% moisture.

The remaining soluble protein after a 99% inactivation of lipoxygenase was plotted against the inverse of the absolute temperature (Fig. 7). This shows that neither buffer improved the retention of soluble protein as compared with soft water. At the higher temperatures of steaming and holding, essentially the same amount of soluble protein remained for soft water and pH 9.8 buffer after a 99% inactivation of lipoxygenase. This is in agreement with Wapinski (1977), who found that steaming (without holding) of cotyledons adjusted to 37% moisture by soak-

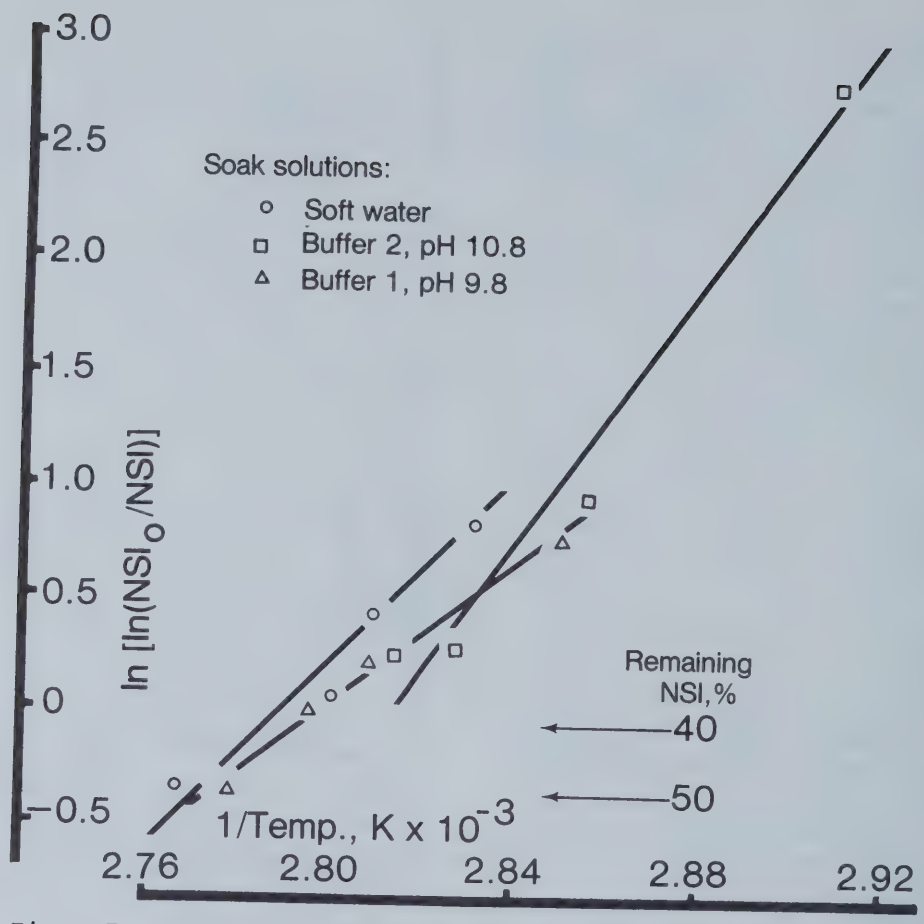

Figure 7. Arrhenius plots showing remaining soluble protein after a 99% reduction in lipoxygenase activity in cotyledons adjusted to an initial moisture content of 32.0% by soaking in soft water or a carbonate buffer.

ing in either a pH 9.6 carbonate buffer or water resulted in approximately the same amount of soluble protein remaining after lipoxygenase inactivation. Thus there was no advantage for our holding period. The pH 9.8 buffer displayed a dramatic difference in its effect on the retention of the soluble protein at 16.3% moisture as compared with that at 32.0% moisture. At 16.3% moisture, the use of the pH 9.8 buffer resulted in a large increase in the remaining soluble protein as compared with soft water; above 91°C, over 70% of the soluble protein was retained after a 99% inactivation of lipoxygenase. However, at 32.0% moisture, no difference in retained soluble protein was observed between the pH 9.8 buffer and soft water.

It is interesting to compare the effects of the carbonate buffers at 16.3% and 32.0%. They displayed differences in 1) the rates of enzyme inactivation, 2) the rates of protein insolubilization, and 3) the amount of soluble protein remaining after a 99% enzyme inactivation. Based on the sorption isotherm of cotyledons (Fig. 1), these differences in the buffer effects on the reaction rates were related primarily to the absence, at 16.3% initial moisture, and the presence, at 32.0% initial moisture, of an additional state of water called solute water (Lang and Steinberg, 1981).

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Research Needs for a New Solvent to Replace n-Hexane in Soybean Oil Extraction

WALTER J. WOLF

The solvent used in the U.S. and many other parts of the world for extracting oil from soybeans is "n-hexane," a hydrocarbon fraction derived from petroleum. Hexane has a boiling range of 63-69°C, is an excellent solvent for vegetable oils, and is essentially free of nitrogen- or sulfur-containing compounds and unsaturated hydrocarbons (Mustakas, 1980). Although widely used as a solvent, hexane has several disadvantages: It is a petroleum product that has become very expensive and may be of limited availability in the future; it is extremely flammable and forms explosive mixtures with air; hexane vapors are toxic, hence maximum concentrations in the workplace must be controlled; recovery of hexane from oil and meal is energy intensive; and recovery of hexane during the conventional extraction process is incomplete, so some of the solvent must be continuously replaced.

Several alternative solvent systems have been examined as possible replacements for hexane, including alcohols, halogenated hydrocarbons, water, and supercritical carbon dioxide.

Extraction of soybeans with ethanol was practiced in Northeast China during the 1930's, and the process was evaluated at the Northern Regional Research Center (NRRC), Peoria, Illinois, in the mid-1940's (Beckel et al., 1948). Low solubility of oil in 95% ethanol at ambient temperatures requires that the extraction be carried out under slight pressure to raise the temperature above 90°C, where the oil and alcohol are completely miscible. However, an oil-rich phase separates when the miscella is cooled, and the oil can be recovered by a nondistillation process with less expenditure of energy than in the usual hexane extraction method. Ethanol extraction also yields light-colored flakes of better flavor than that of hexane-extracted flakes. A disadvantage of ethanol is its tendency to remove moisture from the flakes unless they have been dried to below 3% moisture. The process is not used commercially, but aqueous ethanol currently is utilized in the preparation of protein concentrates from hexane-defatted flakes.

More recently, Shell Development Company (Sullivan et al., 1982) and NRRC (Baker, 1982) have conducted pilot-plant studies on isopropanol as solvent for extracting soybeans. For example, an isopropanol:water (88:12) azeotrope is employed near the boiling point (80.2°C) and, as with ethanol, cooling the miscella results in phase separation that allows recovery of the oil by nondistillation techniques. Residual isopropanol in the oil-rich phase is recovered in an oil stripper, and a semi-refined oil is obtained that does not require degumming and produces smaller amounts of soapstock than hexane-extracted oil. Lower energy consumption than with hexane is claimed for the isopropanol process.

Trichloroethylene was used as a solvent for extraction in Europe from about 1910 to 1930 and in the U.S. in the early 1950's. However, use of this nonflammable solvent was discontinued when it was discovered that it reacted with cysteine to form S-dichlorovinyl derivatives that are toxic to cattle (McKinney et al., 1959).

Use of 1,1,2-trichloro-1,2,2-trifluoroethane as a solvent for extraction of soybean oil has been reported (Temple, 1976). This solvent is nonflammable, low in toxicity, and chemically stable. Hexane is a better oil solvent than the halocarbon at 5-40°C, but at 60°C the differences between the two solvents are very small.

Water has been evaluated as a solvent for recovery of oil from soybeans by workers at Texas A&M University (Lawhon et al., 1981). In this process, finely ground soybeans are mixed with water and the resulting slurry is centrifuged to yield an oil phase, an aqueous phase (containing proteins, soluble sugars, and some oil), and an insoluble residue fraction (cell wall polysaccharides). The protein fraction can be recovered by ultrafiltration followed by spray drying. Disadvantages of the process are

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low yields of oil, the presence of oil in the protein fraction, which may impart poor flavor stability, and the need to operate under more stringent sanitary conditions than needed with hexane processing.

Supercritical carbon dioxide as a solvent for soybean oil has been evaluated recently on a laboratory scale (Friedrich and List, 1982; Friedrich et al., 1982). Oil obtained with this solvent is essentially equal to a degummed, hexane-extracted soybean oil because only very small amounts of phosphatides are extracted. Disadvantages of the technique are the expensive high-pressure equipment and sophisticated technology required for operation with supercritical fluids.

Although a number of solvents for replacing hexane have been examined, none of them have been developed to the point where they are used commercially. Further work will be necessary to find feasible alternatives to the present technology of soybean oil extraction as hexane costs increase.

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DISCUSSION

Guo Xiang-ao asked how many stages would be required for supercritical carbon dioxide extraction.

W. J. Wolf replied that a single stage will suffice. The process simply involves a single stage extraction of a column of flakes followed by phase separation and CO_2 removal by venting. The oil is removed from the bottom of the receiving vessel. In commercial operation the CO_2 would be recycled rather than vented.

Guo Xiang-ao asked if one stage is sufficient.

W. J. Wolf said that based on Dr. Friedrich's experiments, he believed that one stage would be enough. So far, however, work in this area has been limited to laboratory scale, and technology is not yet available for commercial application. CO_2 offers the disadvantage of not improving the flavor of the extracted flakes; they taste grassy and bitter like hexane-extracted flakes. CO_2 does not extract the objectionable flavor components as was originally expected based on the conventional applications of liquid carbon dioxide for the recovery and extraction of flavor compounds.

Guo Xiang-ao asked about energy consumption for this process.

W. J. Wolf said that it is true that the compression stage would be energy demanding; however, the stage of solvent removal by evaporation as in the case of hexane extraction is not required. A complete energy analysis has not been carried out. A problem that is foreseen is the cost and

availibility of commercial scale vessels required for this process in which high pressures are needed.

Wang Jin-ling said that in China they do not have any problems associated with the flavor of soybeans; therefore, flavor is not an important issue. On the other hand, fermented products have provided an alternative to modify the flavor of soybean products.

W. J. Wolf said that in the U.S. the situation is completely different. Industry started out by producing the oil and utilizing the soybean meal for animal feed. Now, we are in the process of trying to make food products and that is why problems have become critical. Industry is making an effort to provide food products suitable and acceptable for the American consumer.

Fermented Soy Foods in the United States

DANJI FUKUSHIMA

At present, three kinds of fermented soyfoods are manufactured in the U.S.: soy sauce, miso, and tempeh. Of these, soy sauce is manufactured in far greater quantities.

Prior to 1973, most of the soy sauce produced in the U.S. was a chemically hydrolyzed product. In 1973, Kikkoman Foods, Inc., opened a plant producing naturally brewed soy sauce, which is marketed nationally through supermarkets. Although chemically hydrolyzed soy sauce is widely consumed, fermented soy sauce has had an annual growth rate of 15%. La Choy and Chun King, the two largest producers of chemical soy sauce, are assumed to have a combined annual production of 20,000 kiloliters. Most of the fermented soy sauce is produced by Kikkoman Foods, Inc., and annual production has reached 19,000 kiloliters.

Fermented soy sauce originated in China thousands of years ago and was introduced into Japan in the sixth century A.D. It is believed that today's Japanese-type soy sauce was established in Japan approximately 400 years ago. Various improvements have been made in the manufacturing processes of soy sauce, especially during the past three decades. As a result, yield and quality have improved markedly.

Soy sauce manufacturing consists of three main processes: koji making, brine fermentation, and refining.

One of the most important improvements was the treatment of whole soybeans or defatted soybean flakes, which increases the yield. The degree of hydrolysis of soybean proteins by *Aspergillus* spp. is influenced by cooking conditions. The higher the temperature, the higher the yield, and the longer the cooking time, the lower the yield (Table 1).

The second improvement increased the enzyme production in koji by using an artificial mutant of *Aspergillus sojae*. This mutant produces more than twice as much proteolytic enzyme and results in an increased yield of soy sauce.

The third improvement was the development of automatic koji-making equipment. The new system includes a continuous cooker, automatic inoculator, automatic mixer, and large perforated shallow vats in closed chambers that are equipped with forced air devices, temperature controls, and mechanical devices for turning the substrate during incubation. With the new equipment we can control conditions to maximize protease activity and prevent contamination by microorganisms which produce an undesirable odor. Comparison between the traditional wooden tray method and the new automatic method is shown in Table 2.

Another improvement involves brine fermentation. *Pediococcus halophillus* and *Saccharomyces ruxii* are important microorganisms in brine fermentation. The moromi mash temperature should be kept around 15°C for the first two months to increase the glutamic acid content. This temperature also increases nitrogen content, although the degree of increase is slight. Initially the pH of moromi mash is 6.7. If the moromi mash is kept at a higher temperature, *Pediococcus halophillus* increases rapidly and the pH drops drastically. This rapid drop can cause a decrease of both the glutamic acid content and the nitrogen content.

The reason is as follows. There are various kinds of proteinases, peptidases, and glutaminases in koji (Fig. 1). The proteins of wheat and soybeans are hydrolyzed by the proteinases of koji into peptides, which are then hydrolyzed by the peptidases of koji into amino acids. The protein molecules of soybeans and wheat contain large amounts of glutamines and glutamic acids. These glutamines and glutamic acids are released into the juice of the moromi mash by the successive digestion by the proteinases and peptidases. The resultant glutamines are changed into glutamic acids by the glu-

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Table 1. Relationship between cooking conditions and yields of soy sauce

Cooking conditions			Chemical analysis of resultant soy sauce			
Pressure (kg/cm^2)	Temperature (°C)	Time (min)	NaCl (g/100ml)	Total nitrogen (g/100ml)	Amino nitrogen (g/100ml)	Yield[a] (%)
0.9	118	45	17.40	1.653	0.817	82.05
2.0	132	5	17.40	1.697	0.837	84.24
6.7	151	2	17.40	1.752	0.839	86.87
7.0	170	0.25	17.40	1.778	0.878	88.26

[a]Yield of nitrogen in hydrolyzed protein as a % of total protein nitrogen.

Table 2. Comparison of protease activity of koji and yields of resultant soy sauce between wooden tray method and automatic equipment method

	Activity of proteases of koji (unit of enzyme activity)	Yield[a] (%)
Wooden tray method	28.40	75.00
Automatic equipment method	40.53	81.00

[a]Yield of nitrogen in hydrolyzed protein as a % of total protein nitrogen.

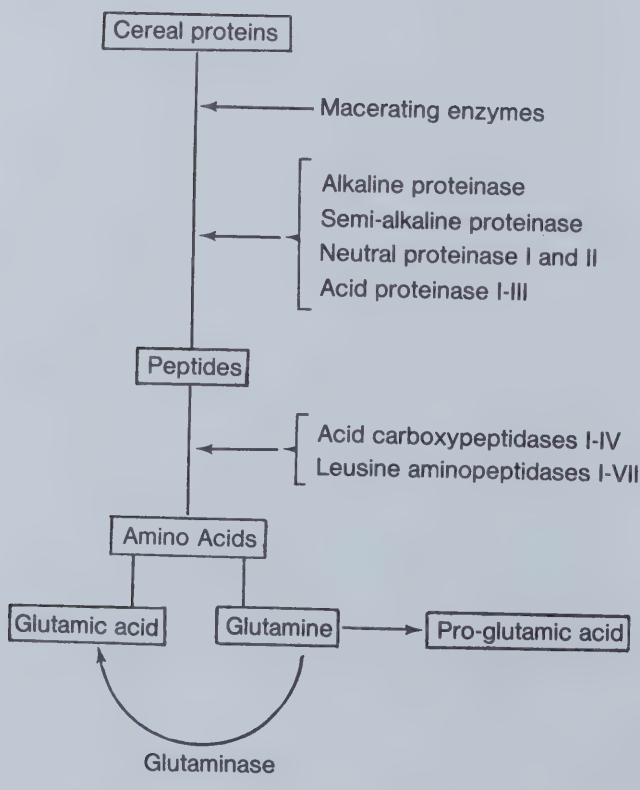

Figure 1. Role of each enzyme in koji during protein hydrolysis.

taminases of the koji. However, if the glutaminase activities in koji are weak, most of the glutamines are changed into pyroglutamic acids through nonenzymatic reaction, resulting in the decrease of the glutamic acid content in the soy sauce. Because glutaminases are inhibited by the acidic pH, the rapid decrease of the pH of the moromi mash also results in the decrease of the glutamic acids in soy sauce. Glutamic acids are one of the most important flavor components of soy sauce, whereas pyroglutamic acids are flavorless. Therefore the action of the glutaminases is indispensable for soy sauce making. If the temperature of the moromi mash is kept low during the first two months, *Pediococcus halophillus* grows slowly. As a result, the pH of the moromi mash decreases very gradually. This allows the glutaminases to function.

The gradual decrease of the pH also brings a slight increase in yield of total nitrogen in the soy sauce. The proteins of the soybeans and wheat are hydrolzyed in the moromi mash by proteinases in the koji. In this hydrolysis process, the alkaline proteinase and neutral proteinase I contained in the koji play a major role in the solubilization of proteins. These enzymes, which are major contributors to yield of total nitrogen, are not active enough in an acidic pH, leading to a yield decrease.

Miso and tempeh are produced in small amounts in the U.S. In 1981, the Soy Crafters Association and the Soy Foods Center estimated that 1,814 metric tons of miso and 454 metric tons of tempeh are produced annually. Tempeh production and consumption are increasing rapidly. To produce tempeh, whole cooked soybeans are inoculated with *Rhizopus oligosporus* and kept for 18 hours at 28-30° C. The soybeans are then deep-fat fried. Tempeh fermentation is quick and easy, and the product is nutritious and tasty. Production is expected to increase.

DISCUSSION

Wang Jin-ling stated that although there is a long tradition of soyfood use in China, China can acquire a great deal of knowledge from Japan.

L.S. Wei said that Japanese technology is very modern and presents a good example of soybean commercialization.

A.J. Siedler stated that although it is sometimes difficult to change consumer's acceptance of a product, it is nevertheless possible. For instance, the quality of sausage has been extensively modified through the years by the introduction of new manufacturing techniques. In a similar way, new products can be introduced into the American market. For instance, several large corporations are becoming interested in the industrialization of tofu.

L.S. Wei said that tofu production is a fast-growing industry. However, one of the problems associated with tofu is its keeping quality over extended periods of time. Tofu manufacturing is very time-consuming, and product stabilization would be a production breakthrough. When this happens, the small businesses that manufacture tofu would become a thing of the past. In China and other countries of southeast Asia, tofu is manufactured in small operations and almost on a daily basis because of the poor stability of the product.

Effect of Enzyme Inactivation on the Extracted Soybean Meal and Oil

LUN SHIN WEI

Because enzyme activity can be detrimental to both oil and meal, the objective of this work was to study the effect of moist heat enzyme inactivation prior to cracking on stability of the crude oil and flavor acceptance of the meal obtained after solvent extraction.

Soybeans were steam-heated at various moisture contents and times to determine optimal conditions for inactivation of the enzyme system. Oxidative stability of the oil from heat-treated beans was increased as determined by the Swift stability test (Mehlenbacher, 1960) and a sensory evaluation. Sensory blandness ratings of the heat-treated meal were superior to those from raw beans. Thus, steam-heat treatment of soybeans prior to extraction was beneficial to quality of both oil and flake.

MATERIALS AND METHODS

Oil Extraction

Seeds of several cultivars were dry cleaned and stored at 1°C until used.

Conventional oil extraction was simulated in the laboratory from flakes prepared from both enzyme-active and inactive soybeans. The dry soybeans were cracked with a fluted roll into six to eight pieces per soybean. The hulls were removed, and the meats conditioned in a steam chest for 30 minutes at 90-95% relative humidity at 60-65°C and finally rolled between preheated smooth rolls to flakes 0.0254 to 0.0305 cm thick. The flakes were held in an insulated container for 15 minutes to simulate the delays between flaking and extraction. One kg of flakes was immersed in 5 liters of hexane and maintained for 15 minutes at 55°C. The flakes then were drained of miscella, and two additional extractions of the same flakes were done in the same manner.

Oil Processing and Evaluation

The combined miscellas were evaporated to a volume of 600 ml to remove fine particles of soy solids prior to vacuum filtration. Residual solvent was removed in a rotary vacuum evaporator.

The oil was examined for oxidative stability by the Swift stability test. Oil was heated in a boiling water bath with air at a constant flow rate bubbling through the oil. The exhaust air from the tubes was ducted to openings for sensory assessment by a trained panel. Panel evaluation sessions were held at intervals throughout the time that the oils were heated. In addition, samples of oil were withdrawn at intervals for determination of peroxide value, using the A.O.C.S. method (Mehlenbacher, 1960).

Meal Processing and Evaluation

The extracted flake was desolventized by evaporation at ambient temperature (20°C), with removal of final solvent traces carried out by air flushing of thin layers of flake.

Part of the extracted flake was closed in a can and heat-treated to inactivate trypsin inhibitor. For flakes from raw soybeans a process for 30 minutes at 120°C was found to be adequate as judged by gelatin hydrolysis, a modification of the Kunitz procedure reported by Kwok (1972). For the flakes from heat-treated beans, a certain amount of heat inactivation had already occurred so that a further 10 minutes at 100°C was all that was needed to completely inactivate the residual trypsin inhibitor.

The extracted flake was evaluated by a trained 15-member sensory panel in two ways. The first method involved presentation of a 1:2::ground flake:water paste, colored to mask visual variations. A triangle difference test was used to determine whether panelists could consistently differentiate the two flake samples. Preference was recorded

L. S. Wei is professor of food science, UIUC. This paper, in a longer form, was first published in 1981 in the Journal of the American Oil Chemists' Society 58:578-583.

of those panelists correctly identifying the odd sample in the triangle test. The second technique was to "dilute" the ground flakes to various degrees with precooked, drum-dried rice. Panelists again were asked to identify the odd sample in triangle comparison tests. Other conditions and analysis of results were as given by Larmond (1977).

Enzyme Analyses

Residual lipoxygenase level in the heated soybeans was determined by a technique described by Surrey (1964) as modified by Lao (1971). Linoleate in buffer was reacted with the enzyme, the increase in conjugated dienes determined using absorbance at 234 nm., the rate of diene formation was calculated, and the results related to the amount of dry soy solids present per ml of reaction mixture.

RESULTS AND DISCUSSION

Enzyme Inactivation Studies

The optimum conditions for lipoxygenase inactivation in the whole beans using live steam at atmospheric pressure were determined. Three factors were examined: bean cultivar, bean moisture content, and heating time.

Heating Time

Hark cultivar whole soybeans at 8% moisture content were heated for various times, and residual enzyme activity was determined. As expected, a linear decrease in residual activity as time of exposure increased indicated a first-order reaction rate. Similar results were obtained by Farkas and Goldblith (1962).

Moisture Content

Hark cultivar soybeans were hydrated to various moisture levels, heated for various lengths of time, and assayed for lipoxygenase. A linear relation was obtained between log of residual activity and heating time. These data were extrapolated to determine time for complete inactivation at each moisture content. Since the lowest level of lipoxygenase activity that could be measured by this method was 0.01 unit/mg of soy solids, this level was selected as the "endpoint." Based on 20 units originally present, this represents 99.95% inactivation. The results are shown in Figure 1. Inactivation time decreased slowly until moisture was above 18% and then decreased rapidly as moisture was further increased.

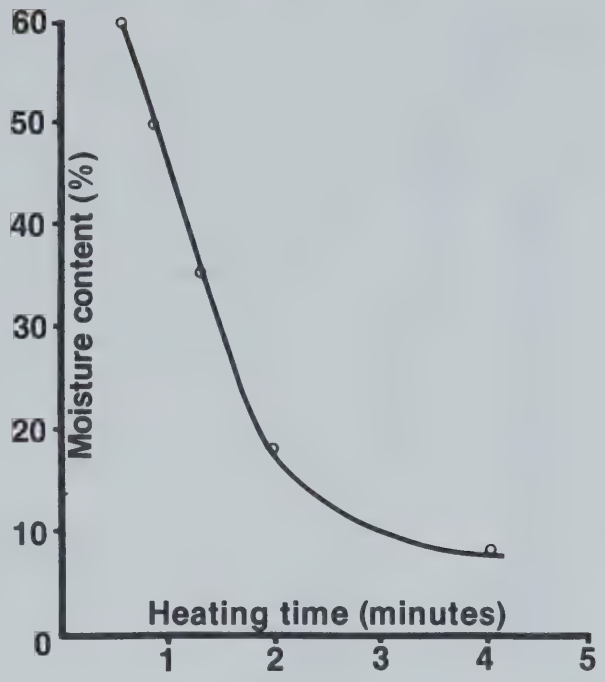

Figure 1. Effect of moisture content on the time required for complete inactivation of lipoxygenase in whole Hark soybeans during steaming at 100°C.

Cultivar

Six cultivars (Amsoy, Bragg, Clark, Corsoy, Hark, and Wayne) were obtained from storage at moisture contents ranging from 5.5% to 8.5%. Clark, Amsoy, and Bragg appeared to contain more heat-resistant lipoxygenase than the other cultivars. However, except for the Wayne cultivar, inactivation rate correlates with moisture content rather than with cultivar, with high moisture requiring less inactivation time. After hydrating all the cultivars to 14-20% moisture, inactivation rates were essentially the same, and time of complete lipoxygenase inactivation was reduced to 1.5 minutes or less (Fig. 2).

Sensory Evaluations

A trained panel was presented with samples prepared by heating 18% moisture content Hark cultivar soybeans for various times and grinding to a 1:10 slurry with water. The panel was instructed to score 5 for the off-flavor in raw beans and 0 for no detectable off-flavor (as in beans boiled for 30 minutes). After one minute of heating, the Hark soybeans at 18% moisture should have shown complete inactivation (Fig. 2) but the organoleptic data here show that the sample at one minute heating still contained off-

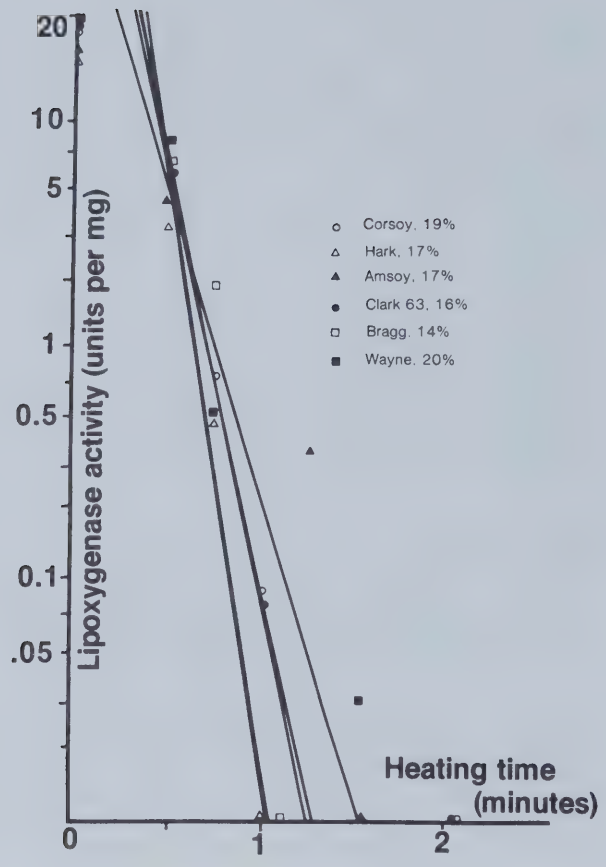

Figure 2. Inactivation of lipoxygenase in several soybean cultivars at increased moisture content by heating the whole bean in steam at 100°C.

flavor (Fig. 3). The off-flavor continued to decrease with heating time and reached a minimum value after ten minutes. Thus apparent enzyme activity is detectable at longer heating times by taste test than by chemical analysis. Based on these results, the enxyme inactivation procedure used for the oil extraction studies was to hydrate the soybeans to 20% moisture and steam for 10 minutes at atmospheric pressure.

Oil Evaluation

The residual oil contents averaged 1.4% for the flakes from raw beans and 2.0% for heat-treated beans. Industrially extracted toasted soy meal oil contents are about 1.0% to 1.5%.

The peroxide value data from the Swift stability test on the oils are presented in Figure 4. After 40 hours, the blanched bean oils had lower peroxide values than the raw bean oils, using a peroxide value of 100 as indicative of rancidity. Stability values of 56 hours for raw bean oil and 62 hours for heated bean oil were obtained.

Sensory assessment of rancidity by the Swift test had considerable variability, inherent in subjective analyses. However, when the data are pooled (over 1,200 individual judgments) it is possible to discern differences between the two oils (Fig. 5). After a slight initial rise in sensory score, both oils maintained similar scores from hour 16 to hour 40, with the blanched bean oils having slightly higher ratings than the raw bean oils. After 40 to 43 hours of heating, the raw bean oils began to drop in score, and thereafter dropped steadily as heating continued, reaching a value of 2.4 after 80 hours of heating. The blanched beans oils began a decrease in score after 51 to 55 hours of heating, over 8 hours longer than the raw bean oils. The blanched bean oils fell in score at the same rate as the raw bean oils and reached a value of 4.0 when the heating was terminated after 80 hours. Blanched bean oils resisted oxidation for 8 hours longer than the raw bean oils (51 hours against 43 hours). These results agree with the peroxide value data (Fig. 4).

These data indicate a quality advantage for oil extracted from enzyme inactivated soybeans. Work with oils from damaged soybeans by List et al. (1977) supports this conclusion. They reported that the stability of refined oil from damaged soybeans was poor.

Meal Evaluation

The extracted flake from raw and blanched beans was examined in a triangle difference test to establish whether a detectable difference in taste existed. The ground flake was prepared from flakes heated (after completion of the extraction process) for 2 minutes at 100°C to complete solvent removal. This treatment also inactivated the residual lipoxygenase in the raw bean flakes. Consequently, flavor differences were formed prior to oil extraction. Of 24 judgments, 21 were identified correctly, demonstrating a significant ($\underline{P}$ = 0.001) difference in flavor. Of the tasters correctly identifying the odd sample, a majority preferred the meal from blanched beans.

Extracted flakes were evaluated further after additional heating to inactivate the residual trypsin inhibitor. This was achieved by heating the blanched extracted flakes for 10 minutes at 100°C. The raw bean flakes required a process of 30 minutes at 120°C, similar to the conditions used industrially. The flakes were evaluated by a taste panel. This involved admixing the flours in varying proportions with precooked, drum-dried rice. Triangle difference tests were used to determine the high-

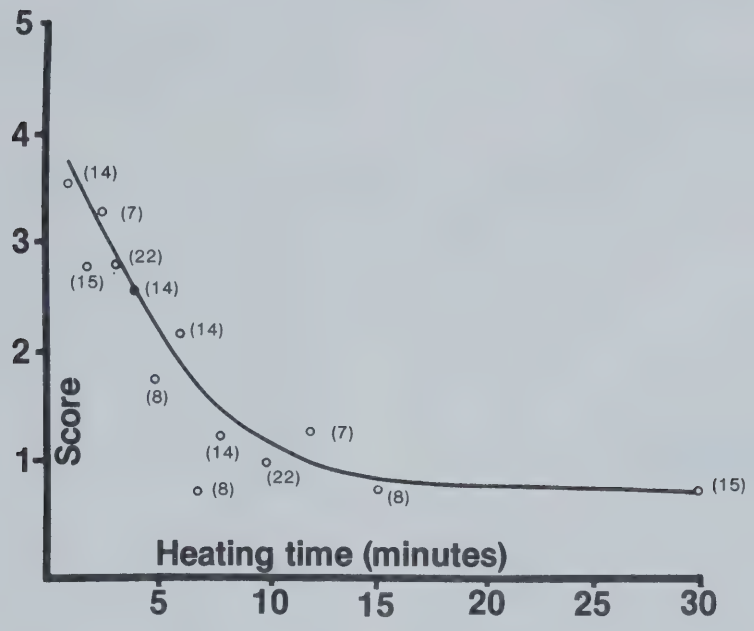

Figure 3. Mean sensory score at 10% solids slurries prepared from Hark soybeans at 18% moisture heated in steam for various times at 100°C. Number of judgments in parentheses. A score of 0 indicates no off-flavors and 5 indicates raw off-flavors.

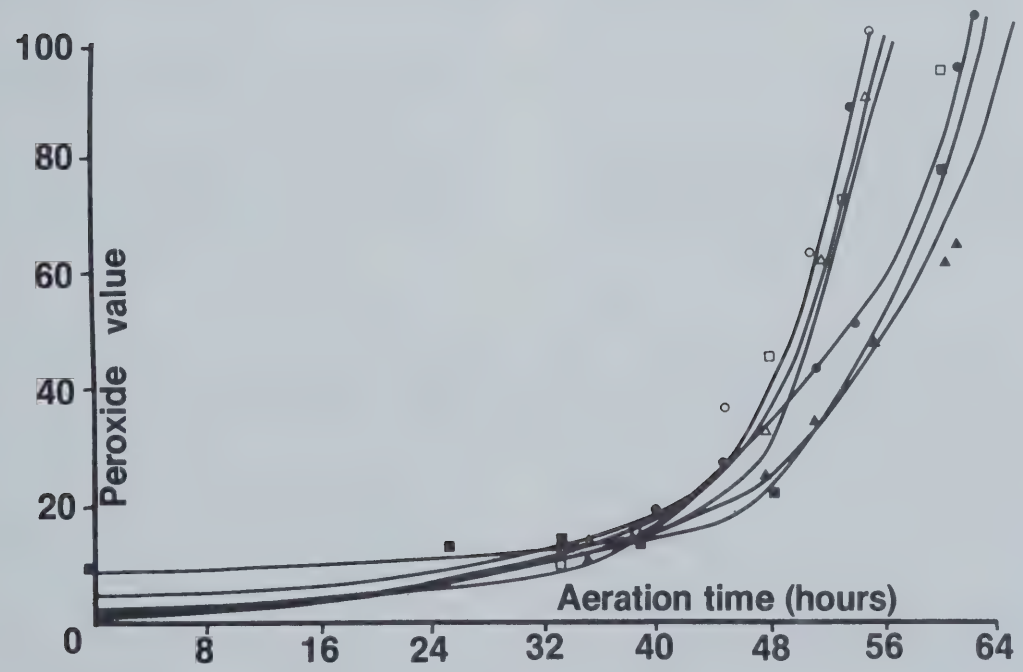

Figure 4. Peroxide values of soybean oils extracted from raw and blanched beans and aerated for various times at 100°C. Each of the three symbols is a different replication. Open symbols = raw and closed symbols = heated.

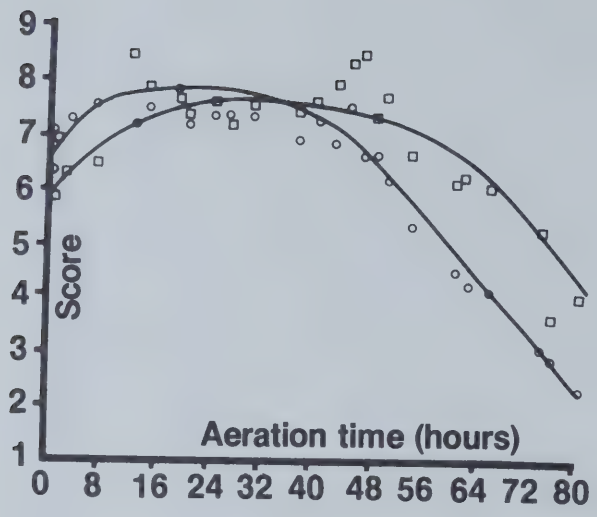

Figure 5. Mean sensory rancidity score (three replicates) of soybean oils obtained from raw (circles) and heated (squares) soybeans and aerated for various times at 100°C. A score of 9 indicates no rancidity and 1 very rancid.

est level of incorporation at which the mixtures could not be distinguished from the rice alone (Table 1). It was found that 5% of raw defatted soybean flour adversely affected the taste, but as much as 15% of the blanched defatted soybean flour could be incorporated without affecting flavor of the rice ($\underline{P} = 0.05$).

Economics

One cost consideration is that the soybeans must be hydrated to about 18% moisture for heat treatment. Since this moisture is too high for oil extraction, soybeans must be dried to about 12%. Another cost consideration is that the yield of crude oil from enzyme inactivatived soybeans was reduced by 0.5% out of about 20%.

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Table 1. Triangle test of comparison of blandness of fat-free soy flour produced from raw and blanched soybeans in rice mixtures compared with rice alone

Flour sample	Number of judgements	Number of correct judgements	Number of correct judgements needed for significance at the 5% level
3% raw flour	6	1	5
5% raw flour	19	11	11
6% raw flour	13	8	8
12% blanched flour	13	6	8
15% blanched flour	19	9	11
20% blanched flour	6	5	5

Utilization of Soybeans in Swine Diets

GILBERT R. HOLLIS

Soybeans are the largest single source of supplemental protein in the U.S. livestock industry. Today, most of the soybeans used for livestock feeding are processed by the solvent-extraction method, which removes all but about 0.5% of the oil. The remaining soybean meal contains 43% to 50% crude protein, approximately 2,900 kilocalories of metabolizable energy per kg, and 2.7% to 3.5% lysine.

There has been considerable interest by many livestock producers in using full-fat soybeans as both a dietary protein and energy source. The whole soybean contains approximately 37% protein, 3,600 kilocalories of metabolizable energy per kg (for swine), and 2.4% lysine. Full-fat soybeans can be used especially when high-energy diets are desired and supplemental oil or fat is unavailable, or when the use of fat meets some opposition due to handling and mixing problems.

However, soybeans must be heat processed to make them an acceptable feed for pigs. Raw soybeans contain the enzyme urease, which is a problem for cattle on urea supplements, and antitrypsin, a powerful growth inhibitor affecting swine and poultry. Both of these factors are destroyed when soybeans are processed properly, whether for soybean meal or by extrusion or roasting.

Sheppard et al. (1967) compared the performance of baby pigs on raw soybean and solvent soybean meal diets. There was a significant ($P<.01$) growth depression and reduced efficiency for pigs consuming the raw soybeans (Table 1).

Research at the University of Illinois at Urbana-Champaign (Jensen et al., 1970a; Jensen et al., 1970b; Jensen et al., 1971; and Carlisle et al., 1973) demonstrated that properly heated soybeans were used efficiently by growing-finishing and gestating swine. But to effectively use heated soybeans as a replacement for soybean meal it is essential to exercise rigid control over the heating and diet formulation.

To obtain a quality full-fat soybean product, it is necessary to heat the soybeans to reduce the proteolytic-inhibiting substances present in the raw soybeans. For optimum quality, soybeans cooked by the dry heating method (roasted) should be heated 3 to 5 minutes at an exit temperature of 115° to 127°C.

The extrusion process is one in which heat and pressure are developed by passing the soybean through a barrel with increasing restrictions by means of a screw. This causes the heating of the soybean by attrition and pressure. The resulting product is discharged into the atmosphere where a sudden decrease in pressure results in expansion. Heating through the extruder acts to detoxify or denature the antinutritive features and improves protein availability. Expansion causes the oil cell to rupture, and as the product cools the oil is absorbed into the cells of the soybean. Expansion also decreases the density of the product. Extruded soybeans should have an exit temperature of 138°C to insure maximum feedlot performance.

Hanke et al. (1972) compared roasted, extruded, and raw soybeans with soybean meal for growing and finishing pigs. Their data emphasize the improved efficiency due to the fat content of the whole processed soybeans and the significantly poorer performance of the pigs on the raw soybean diets (Table 2). Extruded soybeans produced slightly poorer gains for growing pigs ($P<.05$) but not for finishing pigs (56 to 95 kg).

However, further research at UIUC as well as other agricultural experiment stations (Wahlstrom et al., 1971; Seerley et al., 1974; Jurgens and Helgren, 1982) has shown that properly heated full-fat soybeans are an excellent feed source for swine. Growing and finishing pigs have been able to use the protein and fat in the whole beans as efficiently as the protein in soybean meal. However, the oil in whole soybeans is not used efficiently by the weanling pig. Carcasses of pigs fed heat-treated whole soybeans tend to be softer with a higher percentage of unsaturated fatty acids. These differences are small, however, with no apparent problems, especially in meat-type animals.

Whole cooked soybeans are lower in protein and carbohydrates and higher in fat

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Table 1. Raw soybeans for pigs with and without antibiotics

	Raw soybeans			Soybean meal		
	O	PS	PSON	O	PS	PSON
Average daily gain,kg[a]	0.16	0.24	0.20	0.46	0.44	0.52
Feed per kg gain, kg	3.51	2.62	3.35	1.55	1.47	1.53

O = Oxytetracycline; PS = Pen-Strep; N = Neomycin.
[a]Difference between raw soybeans and soybean meal was significant at the 1% level. Difference for raw soybeans with antibiotics and without antibiotics was significant at the 5% level.

Table 2. Effect of soybean processing for growing-finishing swine

	Processing method			
	Soybean meal	Dry roasted	Extruded	Raw
		(25-56 kg)		
Average daily gain, kg	0.79[a]	0.79[a]	0.76[b]	--
Feed per kg gain, kg	2.70[a]	2.56[b]	2.50[b]	--
		(56-95 kg)		
Average daily gain, kg	0.79[a]	0.84[a]	0.84[a]	0.64[b]
Feed per kg gain, kg	3.57[a]	3.45[a]	3.45[a]	4.00[b]

[a,b] Items with different superscripts are significantly different at the 5% level.
Adapted from: Proceedings of the 1981 Profit Symposium, Essential Elements of Efficiency. National Pork Producers Council.

than solvent-extracted soybean meal (Table 3). Because of this lower protein concentration, additional quantities of heat-treated soybeans must be added to swine diets to provide equivalent amounts of protein provided from the soybean meal (Table 4). Whole soybeans contain 18 times more fat than soybean meal. This fat or oil is 2.25 times as concentrated in energy as the carbohydrate or starch from maize. Since this oil can be used by pigs as a source of energy, the energy level of diets using whole, heated soybeans is higher than in diets using commercial soybean meal (Table 4). Because of this greater energy concentration, there is a 4% to 6% improvement in feed conversion when feeding heat-treated whole soybeans compared with soybean meal.

The protein (amino acid) needs of the pig are related directly to the amount of energy in the diet. Pigs fed diets with more energy will not consume as much feed. Hence, with higher levels of dietary energy provided from the whole treated soybeans, additional protein must be supplied to keep the protein:calorie ratio at an optimum level. Therefore, diets containing whole soybeans also must contain more protein than comparable diets using soybean meal. Examples of diets using soybean meal and full-fat heated soybeans are shown in Table 4.

Feedlot performance achieved with soybean meal or cooked soybeans depends primarily upon the quality of the beans initially used and upon proper processing techniques in their preparation. Commercially processed soybean meal is checked periodically for product quality, whereas it is more difficult for swine producers and small processors to know the quality of their heated whole soybeans.

The merits of using whole heat-treated soybeans in farm mixing situations instead of commercially prepared soybean meal depend upon several factors. Pig performance can be expected to be about equal with both products. Thus the decision must be in relation to cost savings. Soybeans may be home-grown and used on the farm or purchased at harvest when they are normally lower in cost. However, this process must outweigh the disadvantages, which include increased storage bin capacity, equipment to heat the beans, energy costs of cooking, and avail-

Table 3. Comparative nutritive values of whole soybeans and solvent-extracted soybean meal

Content	Whole soybeans (%)	Soybean meal (%)
Crude protein	37.00	44.00
Crude fat	18.00	1.00
Carbohydrate	30.00	40.00
Lysine	2.40	2.70
Calcium	0.25	0.25
Phosphorus	0.58	0.60

Table 4. Rations comparing soybean meal and heat-treated soybeans

Ingredients	Soybean meal (kg)	Heat-treated whole soybeans (kg)
Maize	825	760
Soybean meal, 44%	150	--
Soybeans, heat-treated	--	215
Mineral-vitamin premix	25	25
Total	1,000	1,000
Protein	14.0%	14.8%
Metabolizable energy, kcal/kg	3,150	3,250

able labor. Normally, the added energy gain in swine by feeding full-fat soybeans is offset by the energy cost of processing the soybeans for use. Dietary cost advantages will vary from year to year and by locality.

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Soybeans in Poultry Nutrition

DONALD J. BRAY

During the last 50 years, soybeans have become a major source of supplemental protein in U.S. poultry diets, and the same trend is evident throughout the world. This has been made possible by a series of basic and applied experiments conducted at state agricultural experiment stations, in the USDA, and in industrial research laboratories. Through experimentation we identified the qualities of the soybean that limited its usefulness in the diets of poultry and livestock. Based on this information, soybeans and soybean products have been modified to increase their usefulness not only in poultry and livestock diets, but also as human food.

It first became feasible and desirable to incorporate the soybean into U.S. crop culture as the demand for vegetable oils developed. At the same time, the rapidly developing poultry industry was exhausting the limited supply of animal and plant protein concentrates available to it. Through research we were gaining a better understanding of the critical vitamin, mineral, and amino acid needs of poultry. Much of the previous mystique about the need for specific feedstuffs in poultry diets could then be explained in terms of specific nutrients. These could often be provided from alternative and often more economic sources.

Factors that limit the usefulness of fat-extracted soybeans (soybean meal) in poultry diets include many moieties, several of which can be deactivated by heating the meal to 110°C following extraction. Both underheating and overheating reduce the feeding value. When meal is underheated, the digestibility of proteins and other nutrients is reduced and growth rate and egg production are depressed. The pancreas also increases in size. Overheating tends to produce protein (amino acid) complexes with carbohydrates that are not digested. Uniformity of heating within and between batches is imperative to produce an acceptable and dependable product. In commercial production many laboratory tests are available to detect errors in heating, including a simple evaluation of the product color.

As in other plant materials, phosphorus is poorly available because of the presence of phytic acid. This is corrected by supplementing the diet with extra phosphorus from a nonplant source such as defluorinated rock phosphate or dicalcium phosphate.

Soybean meal protein is deficient in the sulfur-containing amino acids methionine and cystine. Although maize protein is a relatively good source of these amino acids, maize-soya diets usually are deficient in sulfur-containing amino acids, especially for the young, rapidly growing meat-type chicken. The extensive use of maize and soybean meal in U.S. poultry diets has stimulated the industry to develop methods of synthesizing methionine and methionine-like compounds to supplement maize-soya diets. Dietary levels of only 0.05-0.10% of either methionine or one of its active analogues are required in maize-soya broiler diets. Layer diets are less deficient than broiler diets in sulfur-containing amino acids.

Among factors that favor the use of soybean meal in poultry diets is its high content of the amino acids lysine and tryptophan. It is higher in these two amino acids than most plant proteins. Since maize protein is deficient in these two amino acids, the two feedstuffs complement each other in providing a balance of essential amino acids.

Ground and heated whole soybeans (unextracted) can be fed to poultry when it is economic to do so. This product is lower in protein and higher in energy than soybean meal and produces mixed feeds with different flow and pelleting properties. Few soybeans are used in this way today. Should the world demand for soybean oil decrease to the point where it is no longer profitable to extract soybean oil, the use of whole soybeans in poultry diets is a possibility.

The continued use of soybean products in poultry diets is dependent upon: (1) the development of alternative, more economic,

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and acceptable protein and amino acid sources, (2) continued research and development leading to more efficient production and processing of soybeans for use in poultry diets at minimal costs, and (3) more extensive use of soybeans directly by man.

From the international perspective, scientists and those in the food industries have much to gain from pooling their technologies and perceptions of where soybeans fit into the food chain. As new concepts and hypotheses are generated in the process, it may be that changes in soybean culture and utilization will be more dramatic in the next 50 years than in the past 50 years.

DISCUSSION

Wang Jin-ling stated that the use of whole soybeans as animal feed in China is inconceivable. In fact, one of the critical needs is vegetable oil.

Guo Xiang-ao asked if there were problems associated with the level of hexane remaining in the meal when solvent-extracted meal was used as animal feed.

D. W. Johnson said no, the normal level of hexane in soybean meal is approximately 50 ppm; therefore, it would not be a problem.

Guo Xiang-ao said that according to the pop test, a level of 400 ppm would be expected.

E. D. Kellogg replied that in the American market, a level of 50 ppm of hexane in soybean meals is normally found.

A. J. Siedler added that there are no regulations as far as the remaining level of hexane.

E. D. Kellogg asked how much of the soybean meal production in China is fed to animals.

Wang Jin-ling replied that first of all, the soybean cake is a byproduct that is exported to Japan and other countries. In the south of China, most soybeans are used as food, which has been a long tradition. Black soybeans are fed to mules and other farm animals.

In the northern part of China, where there is a shortage of vegetable oil, soybeans would never be used as feed. In some circumstances the cake may be used as feed.

G. R. Hollis added that in the U.S. the use of whole soybeans for animal feed is very rare.

Guo Xiang-ao said that in the case of swine for instance, whole soybeans should not be used in order to assure leaner pork.

D. J. Bray agreed, saying that a change in unsaturated fatty acids has been observed in the fat of animals fed whole soybeans. In poultry, a similar result is observed when whole soybeans are used as feed. Changes in the egg yolk have also been detected, but are not significant in terms of how they affect the acceptability and nutritional value of eggs.

D. W. Johnson said that many types of isolates are currently available in the U.S. market. These different products are manufactured having different properties and are therefore geared to different applications.

Cultural Practices Working Group Session

Convener: Donald A. Holt

Reporter: Emerson D. Nafziger

Soybean Production Practices

GARY E. PEPPER

Many production variables influence soybean yields, including cultivar, row spacing, planting date and density, and cropping sequences. Production variables and the interaction between them will be reviewed here. Research data cited were generated at the University of Illinois at Urbana-Champaign (UIUC) and other research institutions.

CULTIVARS

Soybeans are grown widely in Illinois, with the most concentrated production area in the central third of the state. The state is approximately 640 km long, and soybeans of maturity groups I to V are used. The maturities of greatest use are II and III.

There are many soybean cultivars within each maturity group. Cultivars occupying most hectarage in 1982 were developed by public institutions such as UIUC and the U.S. Department of Agriculture (USDA). However, soybeans produced by private seed companies are rapidly gaining popularity.

The rapid increase in privately developed soybeans is the direct result of the Plant Variety Protection Act of 1970. The legislation stimulated development of soybeans by private industry because control and distribution of new, unique soybeans are controlled by the originator. Thus, profit can be gained by those who develop superior soybeans. The price charged for privately developed soybeans is determined by the owner (originator) and is based on supply and demand. Cultivars with the greatest potential to improve farmer profits will logically demand the highest price.

For the 1982 cropping year, nearly 400 privately developed soybeans were offered for sale to Illinois farmers. Most were cultivars, but some were blends or brands. At the same time, nearly 40 publicly developed soybeans were available. Private seed companies market both public and privately developed soybeans.

Farmers are faced with the difficult task of identifying the best soybeans for their land. Universities in major soybean-growing states conduct yield tests, and the results are available to farmers free of cost. Private seed companies pay a small fee to the university for each of their lines tested to help support the cost of conducting the tests. Results usually are distributed through county agricultural extension offices.

USDA Uniform Soybean Tests, which test material developed by USDA and university plant breeders, is another source of information. These results are usually distributed to farmers by state soybean specialists. In Illinois, a free publication containing USDA test data is available from the Illinois Crop Improvement Association. The publication, "Soybean Decision Maker," is revised annually.

ROW SPACINGS

Early in the history of U.S. soybean production, very narrow, noncultivated row spacings were used. The crop was planted with a grain drill and used primarily as forage and green manure. As the crop evolved to one grown primarily for grain, wider row spacings were used to facilitate weed control. In the past, researchers demonstrated that a yield advantage was associated with narrow rows. The return to narrow-row planting taking place now has come about because of better weed control with herbicides. Particularly, postemergence herbicides have made weed control possible in row spacings too narrow for inter-row cultivation.

Many researchers in the midwestern U.S. have studied effects of row spacing on soybean yields. As spacing narrows, there is a yield response to a given point, after which yield tends to level off (Fig. 1). Narrowing rows beyond the point where the plateau develops does not result in

G. E. Pepper is assistant professor of soybean extension, UIUC.

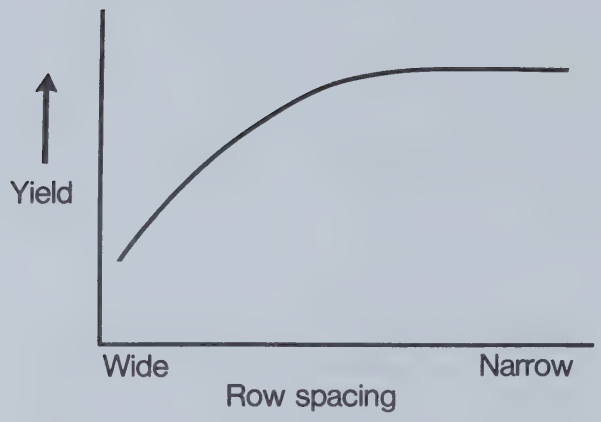

Figure 1. Soybean yield-row spacing relationship.

additional yield. In many studies, a plateau tends to develop once rows close to approximately 37 to 50 cm. This row space response curve (Fig. 1) is typical of May-seeded soybeans but may change with delayed seeding and other cropping variables.

Variables which influence row space responses are latitude, maturity of the soybean planted, and planting date.

A 1978-80 study in Illinois involved a collection of soybeans adapted to northern, central, and southern locations. Yield increases were observed when row spacings were narrowed from 76 cm to 38 cm (Table 1). At a given location, relatively early-maturing cultivars tend to demonstrate greater yield increases with narrowing rows than do late-maturing ones (Table 2).

Seeding in May generally results in the highest soybean yields in major production areas of the U.S. Delays in seeding into June and July produce smaller plants which have less opportunity to utilize the growing season, and consequently yield is reduced. As seeding is delayed and maximum canopy size achieved is reduced, narrow-row benefits to yield tend to increase. A study was done several years ago in Illinois in which planting was done on different dates and in which two row spaces (61 cm and 102 cm) were tested. Absolute highest yields were by planting in May, but the yield increase associated with narrower rows was higher for the late date of planting (Table 3). These results strongly suggest that soybean producers planting late for any reason should try to use the narrowest row possible, considering equipment and weed control problems.

Table 1. Soybean yield response to narrowing row space in Illinois, 1978-80

Location in Illinois	% yield increase for narrow row (38 cm) over 76-cm row
Northern	6
Central	8
Southern	2

SEEDING DATE

The effect of seeding date on soybean yields in the midwestern U.S. is presented in Figure 2. Through most of May, soybean yields are stable. Delays into early June result in noticeable loss in yield potential, with seeding in late June or early July often reducing yields by nearly 50%.

With late seeding, research has shown that a medium- to full-season maturity soybean will have greatest yield potential. Even with full-season cultivars, the threat of frost damage is slight if seeding is completed by early July. This is because late-seeded soybeans will mature in fewer days than those seeded at a more desirable time in May. The photoperiod of late summer, as well as reduction in temperatures associated with the start of fall, results in soybean maturation.

Table 2. Row space response by soybeans of differing maturity, Urbana, Illinois, 1981

Maturity group	Average yield increase for 38-cm rows over 76-cm rows (kg/ha)
II	720[a]
III	592[b]

[a]Average for 45 cultivars.
[b]Average for 44 cultivars.

Table 3. Planting date-row width interactions for soybeans in Illinois

Planting date	Kg/ha for row width of		Narrow row spacing advantage (kg)
	61 cm	102 cm	
May 21	2,571	2,414	157
June 23	2,320	1,944	376

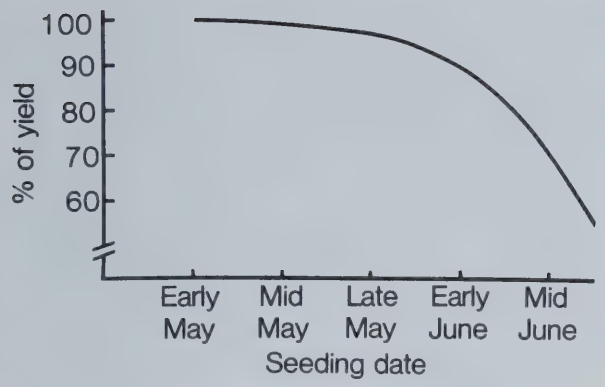

Figure 2. Soybean yield decline associated with delayed planting.

The use of an early-maturing cultivar when seeding late will result in little canopy development prior to bloom. The small canopy will have difficulty providing photosynthate to fill seed, and in addition will stop blooming and mature earlier than a medium- to full-season cultivar. The reduced canopy growth associated with late seeding also can be partially compensated for by increased plant densities (Table 4).

PLANT DENSITY

Whether planting early or late, soybean growers want to seed their crop thickly enough to produce good yields. There is no ideal or perfect plant density for soybean production, but rather a range. Below the suitable range, branches lodge to the ground and the lack of sufficient canopy material result in reduced yield. Above the suitable range, excess stem elongation results in lodging and reduced yield. Therefore, it is important for plant densities to be within certain limits (Fig. 3).

The limits of the range in densities which produce equally good yields may depend on the cultivar, row space, and seeding date. Indeterminate cultivars used across the central U.S. usually produce well at densities ranging from 280,000 to 400,000 plants/ha. Seeding rates which establish stands lower than this range may result in inadequate stands. Attempting to establish stands above 400,000 plants/ha is likely to result in lodging. Growers using narrow-row culture most often use stands nearer the 400,000 plants/ha density. If cultivars grown in narrow rows are of a determinate type, stand densities used tend to be above 400,000 plants/ha. These higher densities may or may not have a yield advantage, but under narrow-row, noncultivated systems, they are used to help insure rapid development of a dense canopy which helps shade weeds.

Table 4. Plant density effect on yield of double-cropped soybeans

Plants/m of row[a]	Yield (kg/ha)
15	2,890
24	3,226
33	3,898
42	3,629

[a]Row spacing 51 cm.

CROP ROTATIONS

Most soybeans in the midwestern U.S. are grown in rotation with maize. Continuous soybean production does occur in Illinois and other states, but not on a large portion of the total crop area. Soybeans grown year after year on the same field forfeit the yield advantages of soybeans grown in a rotation and simultaneously intensify many pest problems such as weeds, diseases, and soybean cyst nematodes.

The yield advantage for growing soybeans in a rotation rather than on a continuous cropping program is illustrated in Table 5. Why rotated soybeans yield higher has not been fully learned. That point is currently under investigation and may be explained by an allelopathic relationship. It can be speculated that better control of weeds, insects, diseases, and cyst nematodes as a result of crop rotation do a great deal to enhance soybean yields.

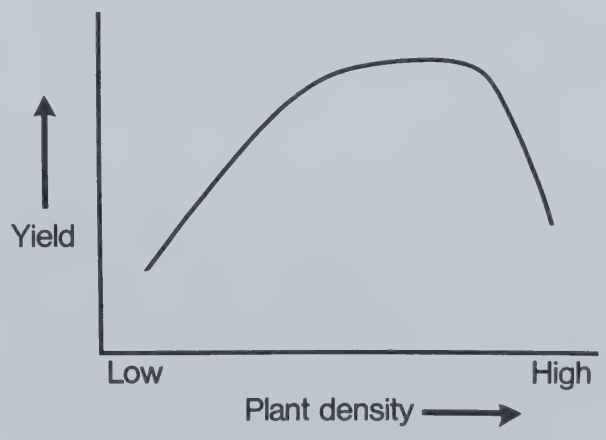

Figure 3. Soybean yield-plant density relationship.

Table 5. Crop rotation effect on soybean yield

Crop sequence	Yield (kg/ha)
Soybeans-soybeans-soybeans	2,957
Maize-maize-soybeans	3,360
Maize-soybeans-wheat	3,427

DOUBLE CROPPING

Many producers of wheat choose to grow soybeans in a double crop program. In Illinois, the majority of the wheat is grown in the southern two-thirds of the state. Wheat maturity in the northern third of Illinois is later than in the south, delaying wheat harvest and planting of double-cropped soybeans. This delay enhances the possibility of frost injury to soybeans.

Double cropping results in roughly 50% of the yield obtainable if soybeans are planted in mid-May. The lack of moisture in the soil at the time of wheat harvest is the major factor limiting establishment of double-cropped soybeans. Soybeans in double cropping must be established rapidly after wheat harvest if any reasonable yield is to be obtained. In years when ample soil moisture is available in late June and early July, a large area is planted in double-cropped soybeans. In dry years, many farmers do not risk seed and herbicide costs on a double crop.

In the early 1980's, 5% to 7% of Illinois soybean hectares were double cropped. In more southern states, a larger portion of total soybean hectares is produced by double cropping.

Good management practices for double cropping include narrow rows, plant densities 50% to 100% higher than those used for May plantings, and medium- to full-season cultivars.

INTERCROPPING

A slightly modified system of producing two crops in a year has been labeled intercropping or relay cropping. In this system the soybeans are planted when wheat is far short of maturity. Wheat row spacing is increased to allow soybean planting and prevent total domination of the soybeans by the wheat. The wider rows for wheat result in some reduction in yield. However, the soybean yield is much higher than with double cropping.

Research at UIUC suggests that wheat can be grown in row spacings of 40 cm without major loss in yield. That same row spacing has proved adequate for seeding soybeans between wheat rows. The best time for seeding soybeans appears to be when wheat reaches the boot to early heading stage. Rather than a calendar date being the indicator of when to plant soybeans, the actual development of the wheat crop should serve as a guide. Planting before the boot stage of wheat is reached may allow soybeans to get too tall before wheat harvest. Cutting of soybean plants when wheat is harvested may considerably reduce the yield. This is especially true if soybeans have reached the bloom stage.

Cultivars yielding best in intercropping studies have full-season maturity. Establishment of any cultivar in intercropping can be difficult or impossible in a dry spring. As with double cropping, moisture is the key to success in producing two crops from one field in a single year.

The soybeans in intercropping are able to use a much larger portion of the growing season (Fig. 4) than in double cropping and consequently yield higher (Table 6). In both systems the wheat matures at the same time. Maturity of soybeans may be slightly different for the two systems, with the double-cropped soybeans maturing last because of a later seeding date.

Wheat yields in the intercropping system (40-cm rows) averaged about 85% as much yield as when grown alone (20-cm rows) (Tables 6 and 7). In 1979, intercropped soybeans yielded only 70% as much as soybeans grown alone. In contrast, the 1981 intercropped soybeans yielded almost as well as the soybeans grown alone. These figures suggest that soybean yields may vary in the intercrop production system, but yields appear to be considerably higher than those of soybeans grown in double cropping.

COMBINING PRACTICES FOR HIGH YIELDS

A few of the production practices or variables related to soybean production have

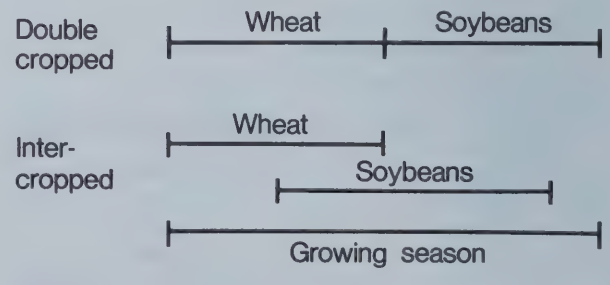

Figure 4. Comparison of double-cropped and intercropped soybeans.

Table 6. Double crop and intercrop yields, Urbana, Illinois, 1979

Cropping program	Yield (kg/ha) Wheat	Soybeans
Wheat	6,317	---
Soybeans	---	4,099
Intercrop	4,973	2,822
Double crop	6,317	1,814

Table 7. Intercropping yields at Urbana, Illinois, 1981

Cropping program	Yield (kg/ha) Wheat	Soybeans
Wheat	4,704	---
Soybeans	---	3,226
Intercrop	4,099	3,091

been discussed. Each variable is essential to the pyramid for it to maintain its strength and integrity (Fig. 5). The lack of any of the variables in the foundation layers of the pyramid might result in a collapse. The adjustment of any one variable may result in the need to adjust others to again maintain the pyramid's strength. The ultimate goal of merging soybean production practices into a workable management system is, of course, to maintain high soybean yields.

DISCUSSION

Dong Zhen-da asked which management considerations are important for high soybean yields when double cropping.

G. E. Pepper said that the most important are an early wheat cultivar, narrow soybean rows, and zero-till planting for moisture conservation.

Ma Rhu-hwa asked, in regard to soybean seed, what is the difference between a blend and a brand.

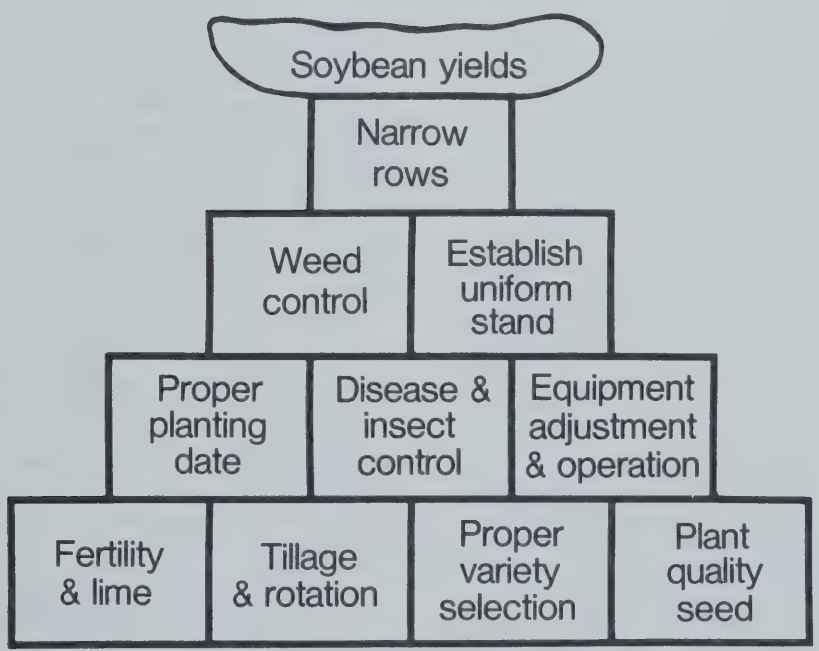

Figure 5. Soybean management pyramid.

G. E. Pepper said that a blend is a mixture, usually of public cultivars. The composition of a blend need not be stated in Illinois. A brand is simply soybean seed with the cultivar not stated and could be a cultivar or a blend.

Ma Rhu-hwa asked why there might be a preference for private cultivars.

G. E. Pepper said that, first, because there are some good, competitive private cultivars. Secondly, there is often more advertising influence with private cultivars.

Ma Rhu-hwa asked if private and public cultivars compared in tests.

G. E. Pepper said yes, in the statewide testing program.

Ma Rhu-hwa asked if there are laws pertaining to private cultivars.

G. E. Pepper said there are laws governing labeling, but truthfulness of performance claims is not guaranteed.

L. F. Welch stated that comparing the number of public and private cultivars may be misleading, since more hectares of public cultivars are grown.

G. E. Pepper agreed and added that there is a rapid trend toward private cultivars, which were planted on 25% of the soybean land in 1981.

Ma Rhu-hwa asked with so many private cultivars, why is there so much support for university breeding programs?

G. E. Pepper said there are a large number of private cultivars, but each company has only a few. Universities continue to have large, productive breeding programs.

Ma Rhu-hwa stated that private companies do make large investments in their breeding programs.

G. E. Pepper replied that is true.

Sun Huan asked about the future of public cultivar improvement.

G. E. Pepper said it will continue, though the size of the programs is not predictable. One major reason for continuing is to train plant breeders.

D. A. Holt said that private companies will continue to depend on the universities for trained people and new germplasm. In return, private companies will continue to support public efforts.

Reduced Tillage Effects on Soybean Growth and Soil Structure

DONG ZHEN-DA

Thirty percent of the total crop area on state farms in Heilongjiang Province is planted in soybeans. The most common crop rotations are wheat-wheat-soybeans (60%); wheat-miscellaneous crop-soybeans or wheat-soybeans-miscellaneous crop (32%); and wheat-miscellaneous crop-wheat-soybeans (8%). For soybeans grown in these rotation systems, plowing is followed by secondary tillage operations consisting of harrowing and forming ridges. Subsoiling is also practiced when necessary.

Before 1970, the traditional tillage operations in Heilongjiang Province involved a form of reduced tillage consisting of plowing and harrowing with simple implements. During the 1970's, tillage practices used in foreign countries were integrated with traditional tillage practices of northeast China. Currently the dominant tillage systems are moldboard plowing or subsoiling followed by several secondary tillage operations, or planting directly on ridges remaining after harvesting wheat or maize with deep plowing only every two or three years. Several herbicides have become available since 1978 for controlling weeds in soybeans. These herbicides provide broad spectrum weed control, are highly efficient with low toxicity, and have made reduced tillage possible and popular for soybean production.

This paper discusses the effects of two reduced tillage systems on the growth of soybeans and soil structure. Experimental data were obtained from research institutes and state farms under the Baoquanling Administrative Bureau.

SUBSOIL TILLAGE FOR SOYBEANS FOLLOWING WHEAT

Following wheat the subsoil tillage system consists of disking twice and then subsoiling and forming ridges simultaneously. After 15 to 20 days, the ridges are reformed or cultivated to control weeds. Before the ground freezes the ridges are rolled smooth. This tillage practice was used from 1974 to 1980 on the Keshan and Baoquanling state farms. Keshan is located in the western part of the reclaimed area of the province. The Keshan soil is black and produces high soybean yields. The Baoquanling State Farm is located in the eastern part of the reclaimed area and has meadows and chalky soils. Findings on these farms and other experimental plots include:

--Subsoiling results in a mixed soil structure consisting of both compact and loose soil.

--Compared with other tillage systems, the subsoil system resulted in higher yields and soybeans with more numerous and heavier root nodules.

--During the flowering period, the average weight per plant from a subsoil field was 71.2 g as cut and 15.1 g after drying, and the leaf area was 360 cm^2. From a plot that had been plowed, corresponding plant measurements were 43.9 g, 6.6 g, and 192 cm^2, and from a harrowed plot 68.9 g, 10.5 g, and 293 cm^2.

--At Zhahayan State Farm in 1977, soybeans from subsoil plots were 7.8 cm taller than from moldboard-plowed plots. Plant and root weights and number of nodules per plant were also greater from the subsoiled plots.

--Soybean yields were 5.7% higher from subsoiled plots than from moldboard-plowed plots at Keshan State Farm and 10.9% higher in experiments at Zhahayan.

--After subsoiling the soil had excellent water-holding capacity. The loose soil helped hold moisture, while the compact area contributed to capillary action. This combination holds, maintains, and distributes soil moisture and is especially beneficial to soybeans at the seedling stage by promoting uniform and vigorous growth (Table 1). The Research Institute at Baoquanling Administrative Bureau of State Farms found that a

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pool is formed under the ridges after subsoiling. This pool holds rain water, which is utilized by the plants during the summer.
--Subsoiled fields have a slightly lower bulk density than plowed fields (Table 2). The loose soil is beneficial to the growth of soybeans. With subsoiling and ridging, the soil bulk density is higher in the furrow between the ridges than on the ridges. This difference is significant and remains constant throughout the growing period. In plowed fields, bulk density is uniform throughout the tilled zone. However, this density changes during the growing period, becoming more compact during the later stages.
--The subsoiled seedbed had a temperature 1°-1.5°C higher than the plowed seedbed, mostly because the ridges lie 3-4 cm higher than the level plowed fields.
--Subsoiling does not mix the fertile top soil. Nutrients are concentrated at the surface with a good supply of moisture and air, which favors the activity of microorganisms. Phosphate and water-soluble nitrogen are available to plants in the early growth periods (Table 3). In experiments at the Research Institute of Baoquanling Administrative Bureau of State Farms, the soil layer 20-30 cm below the subsoiled ridges had more quick-acting phosphate than plowed fields.
--The ridges and mulch remaining in fields after subsoiling alleviate wind and water erosion. Keshan State Farm was twice hit by a gale in April, 1977. There was 80% less erosion in subsoiled fields than in plowed fields. After a 20.5 mm rainfall, runoff from plowed fields was 7,140 kg/ha more than in subsoiled fields.

Table 1. Soil moisture content in soils in spring with different tillage systems

Date and depth (cm)	Moisture content (%) for three tillage systems		
	Subsoiling	Harrowing	Plowing
May 3, 1975			
0-10	33.6	33.2	34.2
10-20	31.9	30.0	31.5
20-30	33.1	30.3	32.4
Average	32.9	31.2	32.7
April 28, 1977			
0-10	16.1	15.4	15.5
10-20	26.1	25.6	25.0
20-30	25.4	25.4	25.9
Average	22.5	22.1	22.1
April 28, 1978			
0-10	28.0	26.7	19.9
10-20	30.9	32.3	33.6
20-30	30.8	31.0	31.5
Average	29.9	30.0	28.3
Average (0-10)	25.9	25.1	23.2

Table 2. Soil bulk density with different tillage systems

Date and depth (cm)	Density (g/cm^2) for three tillage systems		
	Subsoiling	Harrowing	Plowing
June 20, 1977			
0-10	0.99	1.15	1.09
10-20	1.07	1.06	1.07
20-30	1.10	1.10	1.08
Average	1.05	1.10	1.08
June 25, 1978			
0-10	0.94	0.93	0.91
10-20	1.06	1.11	1.07
20-30	1.05	1.08	1.11
Average	1.02	1.04	1.03

Table 3. Availability of quick-acting nutrients in soils with different tillage systems

Nutrient and depth, cm	Mg/100g of soil in three tillage systems		
	Subsoiling	Harrowing	Plowing
Quick-acting phosphate			
0-10	3.93	4.82	3.05
20-30	2.98	4.45	2.07
Average	3.46	4.64	2.56
Average increase over plowing	+0.90	+2.08	0.00
Water-soluble nitrogen			
0-10	7.90	7.20	9.50
20-30	12.90	10.30	9.20
Average	10.40	8.75	8.35
Average increase over plowing	+2.05	+0.40	0.00

--During the early stages of soybean growth, weed control is critical in subsoiled fields and chemical weed control is essential.
--Records from Baoquanling and Xinhua state farms showed that the cost of land preparation was reduced 12.45-16.30 yuan/ha with subsoiling compared with plowing, and fuel consumption was reduced by 38.8%. The common subsoiling tillage implement is 2.1 m wide and has seven shovels. In one work shift, this machine tilled 7.5 ha, consuming 4.8 kg/ha of fuel. In the same time period, a five-bottom plow tilled 3.5 ha using 13 kg/ha of fuel.

SUBSOIL TILLAGE FOR SOYBEANS FOLLOWING MAIZE

Soybeans are grown after maize in the reclaimed areas of Heilongjiang Province where the growing season is characterized by low temperatures, short frost-free periods, and spring drouth. The tillage practice of subsoiling helps conserve soil moisture and raise soil temperature. This encourages early maturity and increased yields. Since first tested in 1975, this method has increased steadily in popularity. At present, 10-15% of the soybeans grown under Baoquanling and Nenjiang Administrative Bureaus are planted following maize and with subsoil tillage.

With this method it is important to control weeds and maintain the ridges in their original form. After the soil freezes but before a heavy snow, the maize stalks are cut with a heavy-duty chopper. Immediately after the spring thaw, the ridges are cultivated with light rakes to gather weed seeds and young weeds. Then two rows of soybeans, 14-16 cm apart, are planted on each ridge. Ridges are 70 cm apart. Furrows are sub-soiled or cultivated for weed control, and herbicides are also applied.

Data from experiments conducted from 1975 to 1981 at Baoquanling, Zhaoguang, and Keshan state farms showed that this tillage practice had several advantages:
--Final land preparation and crop seeding are accomplished by one machine pass.
--Soil moisture is conserved during spring drouth with nearly 100% seedling survival. At Baoquanling State Farm, soil moisture content was 1.3-4.1% higher in subsoiled fields than in plowed fields. At Zhaoguang State Farm, soil moisture in subsoiled fields was 2.5% greater at planting, 6.6% higher during germination, 8.6% higher at branching, and 7.1% higher at flowering than in plowed fields.
--Seedlings emerged three to seven days earlier and had a higher survival rate. At Baoquanling State Farm, soybeans planted on ridges had more vigorous growth than plants in plowed fields (Table 4).
--Maize is heavily fertilized and a considerable percentage of the fertilizer remains in the soil after harvesting. At Baoquanling State Farm in 1978, maize ridges had 68% more water-soluble nitrogen and 30% more phosphate than plowed fields. At Zhaoguang State Farm, the nitrogen content of maize ridges was 28.9% higher, and the phosphate content was 2.7% higher than in plowed fields. In addition, each hectare contained 5,000-6,000 kg of maize stubble and roots which decomposed and added nutrients to the soil. Tests at the Research Institute of Mudanjiang Administrative Bureau showed maize residue has a nitrogen content of 0.83% and a phosphate content of 0.21%. Thus, the maize residue yields 112.5-127.5 kg/ha of ammonia nitrate and 60-75 kg/ha of calcium superphosphate.
--In May, 1980, Baoquanling State Farm was hit by a strong gale. Plowed fields lost 400 tons/ha of top soil. In fields where soybeans were growing on original maize ridges, soil loss was 87.5% less. During a strong gale at Xinhua State Farm in May, 1979, fields growing soybeans in ridges had 83.4% less soil loss than plowed fields.
--The soil temperature on ridge tops was 0.3°-0.8°C higher than in plowed fields, and soybeans matured three to five days earlier.
--Soybeans grown on original maize ridges had a 5.2-11.5% greater yield than soybeans planted in plowed wheat or maize fields. In some years the yield was 35-40% greater.
--At Baoquanling and Xinhua state farms, fuel consumption was reduced by 85.3% and operating costs reduced 30-37.8 yuan/ha. At Zhaoguang State Farm the cost reduction was 19.5-24 yuan/ha.
--Fewer weeds emerged in fields where soybeans were planted on original maize ridges. Due to raking before planting, weeds emerged primarily in the furrows and could be controlled by mechanical cultivation. In plowed and harrowed fields, weeds could only be controlled by herbicides.

Table 4. Comparison of soybean plants with different tillage systems

Tillage system	Plant height (cm)	Pods/ plant	Seeds/ plant	Plant weight (g)		Root length (cm)		Nodules	
				Above ground	Roots	Tap	Lateral	No.	Weight (g)
Ridge	98	29	42	65	8.2	29	49	88	0.6
Plowing	76	16	33	22	3.4	25	35	61	0.4

DISCUSSION

L. F. Welch asked the name of the equipment described.

Dong Zhen-da said it is a subsoiler.

L. F. Welch said that the water-soluble soil N levels were found to be very high.

Dong Zhen-da said this is because N fertilizer had been added.

D. R. Erickson asked how ridges are formed in this system.

Dong Zhen-da said they are formed during cultivation of the previous crop.

Y. Y. Shalaby asked if the extra yield pays for the tillage.

Dong Zhen-da replied that there is no extra tillage. Tillage is reduced with this system.

D. A. Holt asked if there is only one tillage.

Wang Jin-ling said yes. Only the ridge top is tilled. The ridge then is rebuilt by cultivation.

L. F. Welch asked about the rainfall amount in that area.

Wang Jin-ling replied it is 50 to 60 cm annually, mostly in July and August.

Weed Control in Soybeans

LOYD M. WAX AND FRED W. SLIFE

Soybeans are grown widely in the U.S., but in the past 15 years the areas of production have become more concentrated. Major areas of production are the north-central region (Corn Belt), the southern region (Mississippi Delta), and the southeast region. These three areas produce approximately 90% of the total U.S. production.

The problem weeds in soybeans are primarily annual weeds, although some perennial weeds are common to all three production areas. The specific weeds present are a result of the management system imposed and the climatic adaptation of the weed species. Foxtail (*Setaria* spp.) is the prominent annual grass species in the north-central region, while crabgrass (*Digitaria* spp.) is dominant in both the southern and southeast regions. Annual grass species are more common than annual broadleaf species but since the annual grasses are well controlled, the immediate weed problem is annual broadleaf weeds. Six to eight species are common to each region.

Perennial weeds are present in all regions and occur mainly in localized areas. The exception, Johnsongrass (*Sorghum halepense*), is widespread in both the southern and southeast regions. Uncontrolled infestations can reduce yields 50% or more.

The basic weed control system used in all areas involves chemical control and cultural practices. Some hand-weeding is used to prevent weed seed production. Biological control has developed very slowly in the U.S. in terms of annual weeds in soybeans, but in the past five years considerable research effort has been initiated. We hope it will develop rapidly in order to reduce our dependence on chemical weed control.

Currently we are in the midst of changing tillage practices in all regions of soybean production. Soil conservation has become a prominent theme throughout the U.S. In order to reduce soil erosion, producers are encouraged to leave as much of the previous crop residue on the soil surface as possible. This practice greatly reduces soil erosion, but it also interferes with some of the chemical weed control systems. The need for soil conservation is so critical that weed management systems will have to be adjusted to fulfill this need.

Weed control in soybeans has progressed to where essentially all soybeans receive one or more herbicide applications. In most instances, the soybeans are also rotary-hoed and are cultivated at least once. Under these conditions, losses due to weeds in soybeans have been reduced markedly over the past 10 to 15 years, so that, under optimum conditions, a majority of fields are nearly free of weeds.

Unfortunately, conditions are not always optimum. Further, application and incorporation techniques leave something to be desired, and changing tillage practices tend to create problems with control of existing weed species as well as promoting the growth and development of weed species not normally associated with conventional tillage systems. Thus we seem to have a continuing supply of problems with weeds in soybeans.

The wide variety of herbicides available for preplant incorporation, such as Treflan (trifluralin) for grass control, Sencor or Lexone (metribuzin) for broadleaf control, or a combination for broad spectrum control, continues to provide excellent control under optimum conditions. However, when conditions are less than optimum, growers may expect less-than-perfect results. Practices in use are making outstanding weed control more difficult with these herbicides. Most growers are using less adequate incorporation than was formerly practiced. In most situations (good seedbed, not too much moisture or plant residues) good weed control is being achieved. In less-than-optimum conditions, weed control may not be as good as desired. These kinds of treatments will likely continue to be the mainstay of most weed control programs for the immediate future in

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areas where conventional tillage is used, or in reduced tillage situations where not too much residue is left on the surface.

Preemergence herbicides such as Lasso (alachlor), Dual (metolachlor), Amiben (chloramben), and Lorox (linuron) are applied to the soil surface and are still popular in many areas. When there is adequate rainfall after application, they provide excellent weed control with good crop safety. They remain dependent upon rainfall, however, and may fail completely in the absence of rainfall within a reasonable time after application. Preemergence treatments will likely remain popular for the immediate future in areas where they have been especially popular in recent years.

The greatest increase in herbicide usage in soybeans in recent years has been for postemergence applications over the top of soybeans and weeds early in the season. These treatments, such as Basagran (bentazon) and Blazer (acifluorfen), may provide excellent control of many broadleaf weeds under optimum conditions. Basagran and Blazer, while applied at about the same stage of growth, differ in the species they control. Growers usually consult with experiment station and extension personnel and read labels before making a decision about which of these herbicides is appropriate for a particular situation.

Another area that seems to hold a great deal of promise for the future is the use of postemergence grass killers such as Fusilade (fluazifop) and Poast (sethoxydim). We have evaluated a number of these, and several appear to have extremely high potential for selective postemergence grass control in soybeans. In general, these chemicals are effective at very low rates, in the range of 0.28 kg/ha (active ingredient), have very little soil residue, and do not seem to be markedly affected by weather, or condition or stage of growth of the plants. They have, in our experiments, provided effective and consistent control of annual grasses, and at somewhat higher rates show great potential for control of perennial grasses such as Johnsongrass and quackgrass (*Agropyron repens*).

These postemergence grass killers would seem to have considerable potential for use as a backup treatment in case earlier preplanting or preemergence treatments were not effective. In addition, as a primary treatment, they give the grower the option of selectively controlling annual grasses when, and if, they appear. Growers would probably want to fully assess how consistently effective these treatments are under their conditions before committing a very large area to primary treatment with one of these new herbicides. These new chemicals would seem to have special importance for use in reduced tillage situations where adequate incorporation for preplanting treatments destroys too much residue and preemergence treatments are dependent on rainfall.

The herbicide Roundup (glyphosate) is fairly widely used as a directed treatment over the top of soybeans where it is applied to weeds that have grown taller than soybeans. It is applied with a variety of devices, including recirculating sprayers, rollers, and rope wicks. When applied correctly, it is effective for control of such weeds as Johnsongrass, shattercane (*Sorghum bicolor*), and volunteer maize (*Zea mays*). It is somewhat less effective on several annual and perennial broadleaf weeds. Because some competition has already occurred at the time of treatment, this treatment is not considered a primary treatment, and would be used when earlier treatments allowed some weed escapes.

Certain special problem areas seem to come to attention more often than others and may deserve special mention here. One of these, narrow row or drilled soybeans, seems to be increasing in hectarage and drawing a lot of interest from producers, seed companies, chemical companies, and equipment companies alike. Insofar as weed control is concerned, there are a few extra problems associated with drilled soybeans. The primary problem is simply that the elimination of cultivation results in no backup system in the event that herbicide applications were uneven, or the incorporation pattern was streaked, or in the rare event that the herbicide treatment was just not effective.

On the positive side of drilled soybeans, there are several excellent combinations of herbicides that, when combined with a thick, vigorous stand of drilled soybeans, can result in excellent weed control, easier harvesting, and often a small yield advantage over soybeans grown under the same conditions but in wide rows. There is definitely a place for drilled soybeans, but with the present treatments they are usually planted on land that is not too weedy and is not infested with perennial weeds.

Certain perennial weeds seem to be either remaining stable or increasing their spread under reduced tillage and cultivation practices. Weeds like yellow nutsedge (*Cyperus esculentus*) can be controlled but only when a system involving herbicides, tillage, cultivation, and crop management is ininvolved. Other perennials, such as common milkweed (*Asclepias syriaca*) and hemp dogbane (*Apocynum cannabinum*), continue to remain as real problems with very little means of control in soybeans. Rotation of

soybeans with maize, combined with tillage and the limited chemical control measures available at present, provides barely adequate control at best.

Special weeds such as eastern black nightshade (*Solanum ptycanthum*) seem to come and go and get a lot of attention from farmers. Black nightshade seems to favor moist conditions for germination and growth. The nightshade remains green after a light frost, and the combination of green forage and black berries filled with sticky sap and seeds makes harvesting almost impossible. Further, the berries may remain intact and contaminate seed supplies by their presence or by discoloration of soybean seeds. This is especially troublesome for farmers who are producing seed for replanting.

Black nightshade is relatively tolerant of herbicides in wide use such as Treflan and Sencor or Lexone, so it grows relatively well in those situations where most other weeds have been controlled by herbicides. Several herbicides, such as Dual, Amiben, Lasso, and Blazer, are effective for control of black nightshade; however, they are not usually completely effective, mainly because black nightshade may germinate at various times from April to October. We believe, however, a treatment with one or more of these herbicides in soybeans, combined with a rotation to maize and effective weed control in that crop, can greatly reduce the losses caused by this weed.

There is now available a wide array of chemical treatments for weed control in soybeans, allowing the producer various choices in reducing losses caused by weeds. The newer herbicides on the horizon for postemergence grass control broaden choices even more and promise a bright future for weed control in soybeans.

DISCUSSION

Wang Jin-ling asked if aerial application of herbicides is a common practice.

F. W. Slife said it is common in the south, but limited in the north because of drift and injury problems.

Wang Jin-ling stated that though herbicide use is common in Northeast China, spring drouth limits herbicide effectiveness. There is also a plentiful labor supply for hand-weeding.

S. E. Halbert asked how weeds are controlled in intercropping.

L. M. Wax said that for this we need a long-lasting chemical that is safe and effective on both crops. Control needs to last until development of the soybean canopy; this can be a problem if soybean growth is poor. Dual and Surflan (oryzalin) have worked for grass control, and Modown (bifenox) for broadleaf weeds. We may also need a postemergence grass herbicide.

Wang Jin-ling asked if there is a herbicide for wild rye control.

L. M. Wax said no, but some new postemergence herbicides look promising, particularly with low-volume application.

Qu Ning-kang asked about the nature of weed resistance to herbicides.

L. M. Wax replied that some has probably been acquired and some simply selected for. Most has appeared where high rates of herbicide have been used continuously.

D. A. Holt stated that there also is evidence of enhanced herbicide breakdown in the soil.

L. M. Wax said this could be considered a different type of "resistance," due primarily to microbial degradation.

Sun Huan asked if there are cultivar differences in response to herbicides.

L. M. Wax said yes. For example, we have identified a line that is very susceptible to bentazon, a chemical which soybeans normally tolerate well. Also, lines have been found to vary widely in response to the herbicide metribuzin.

Qu Ning-kang asked if there has been any effort to use genetic engineering to identify resistance.

L. M. Wax said very little work has been done in this area to date, but that genetic engineering work to identify resistance is anticipated in the near future.

Sun Huan asked if any biological weed control work has been done.

L. M. Wax said that more work has been done in the south than in the north. For example, diseases have been found which will help control velvetleaf and northern jointvetch. In the latter case, spores of the disease are marketed commercially.

R. Y. Yih said that ideally we would like to see nonpersistent herbicides used, such as Stam, which is used in rice in both the U.S. and the People's Republic of China. We also need crops resistant to persistant herbicides. However, there has been weed resistance to 2,4-D after prolonged use in wheat in the P.R.C.

F. W. Slife said that in general, weed control now is better than ever before. Herbicides remain the primary method of control. There is a need to diversify control methods to reduce problems associated with continuous herbicide use.

Fertilizer Needs of Soybeans

L. FRED WELCH

Soybean growth depends on genetic and environmental factors. Genetic factors become fixed once the grower selects a particular cultivar. Some environmental factors are controllable, others are partially controllable, and still others are uncontrollable by growers. Sunlight and air temperature are examples of uncontrollable factors. The supply of available elements in soil can be controlled. Since there are so many environmental growth factors which cannot be controlled, we should at least manage well those factors which we can control.

Adding fertilizer increases the probability that the available supply of essential elements is not limiting soybean growth. The term fertilizer in this paper has its commonly used meaning, but it also refers to manure or any other material added to soil to increase the supply of essential elements.

ESSENTIAL ELEMENTS

Soybean grain is composed largely of carbon (C), hydrogen (H), and oxygen (O). These elements are supplied by air and water, so they will not be discussed further in this paper.

Nitrogen (N), phosphorus (P), and potassium (K) have been classified as macroelements. Calcium (Ca), magnesium (Mg), and sulfur (S) are called secondary elements. Zinc (Zn), copper (Cu), boron (B), iron (Fe), molybdenum (Mo), and manganese (Mn) are microelements. (Cobalt (Co) and chloride (Cl) also are sometimes listed as essential microelements.)

The classification scheme does not refer to the importance of the particular element for plant growth, but to the amounts of the elements commonly found in plants. Microelements are just as essential as macroelements for plant growth.

The amount of essential elements contained in soybeans varies considerably for the different elements. For example, 1,633 kg of soybeans contains 29.5 kg of potassium but only 0.1 kg of zinc.

SUPPLIERS OF ESSENTIAL ELEMENTS

Essential elements are supplied to soybeans by soil, fertilizer, and air. Soybeans, in association with bacteria, obtain nitrogen from air for symbiotic fixation.

The total content of essential elements in soybeans is known. Soils differ in their ability to supply essential elements to plants. If the soil is a low supplier, much has to be supplied by added fertilizer. If the soil is a high supplier, little or no fertilizer needs to be added. Chemical soil tests are a means for determining the amount of an element supplied by various soils. However, a chemical test value is meaningful only if it has been calibrated with field results of fertilizer experiments.

NITROGEN IS DIFFERENT

Nitrogen fertilizer rarely increases soybean yields in the U.S. No nitrogen fertilizer is recommended for soybeans grown in Illinois. This recommendation is based on data from many experiments that have included rates, time, and method of nitrogen application. Soybeans have been grown in Illinois for several years. In countries where soybeans are being grown for the first time, the need for nitrogen fertilizer may be different than in Illinois. Also, if soil conditions present an unfavorable environment for *Rhizobium* bacteria, yields could possibly be increased by adding nitrogen. An extremely acid soil is an example of an unfavorable environment.

CHEMICAL SOIL TESTS

Most states in the U.S. provide a soil testing service to growers. The laboratories charge a fee for testing. Although tests can be made for several elements, the most common tests are for P, K, and soil pH.

Soil acidity is controlled by the addition of liming materials such as calcitic and dolomitic limestone. Growers are advised to maintain the soil at about pH 6.

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Once the soil pH is properly adjusted, it is usually not necessary to relime for eight or more years.

P and K do not readily move in soils other than sands and are classified as immobile nutrients. This immobile characteristic means that the quantities of P and K easily can be increased in soil by the addition of fertilizer.

Fertilizer is added for both build-up and maintenance for soils low in P and K. Once soils have reached the desired soil test value, fertilizer is recommended to maintain the level. Maintenance is equal to the amount of P and K contained in the harvested portion of the crop. Some soils may test high enough that fertilizer need not be added, not even a maintenance amount.

A solution of ammonium fluoride and hydrochloric acid is used in Illinois for extracting soil P. Our recommendations for different soil test values are:

Soil test P,

kg/ha	Add P fertilizer for:
<50	Build-up plus maintenance
50-73	Maintenance
>73	None

Exchangeable K is determined for the soil test value. Ammonium acetate is the extracting solution. Our recommendations are:

Soil test K,

kg/ha	Add K fertilizer for:
<336	Build-up plus maintenance
336-448	Maintenance
>448	None

Unless recently built up by high rates of fertilizer, all Illinois soils require periodic addition of P and K fertilizer. Ca and Mg generally are present in ample supply if the pH is properly maintained. No soybean yield increases generally are expected in Illinois from the addition of the other essential elements. That is, Illinois soils can supply the total amounts needed by soybeans. An exception is that Fe and Mn deficiencies sometime occur in soils higher than pH 7.2.

APPLYING FERTILIZER

Most of the fertilizer applied for soybeans is broadcast on the surface and then incorporated into the soil. Soybeans are extremely sensitive to damage from salts. Care must be used to prevent germination damage if fertilizer is applied in a band near the seed.

Maize and soybeans are grown in alternate years on a large hectarage in Illinois. Many growers add all the P and K fertilizer prior to maize, with none added just prior to soybeans. This practice is satisfactory when enough fertilizer is added for both crops with the one application.

IN CONCLUSION

An adequate supply of essential elements is only one of several environmental factors that affect soybean growth. A high level of soil fertility does not guarantee high soybean yields. But a low level does guarantee low yields.

DISCUSSION

D. A. Holt asked if K is used widely in the People's Republic of China.

Qu Ning-kang replied that there is a soil survey in each province, and each county has an experiment station and soil scientist. Results of the survey are supplied to leaders of each production brigade (60 to 70 families). More attention is given to cash crops. K is in short supply, so is allocated carefully according to plan.

L. F. Welch said that visitors from the P.R.C. to Saskatchewan, Canada, indicated that more K is needed.

Qu Ning-kang said that this is true, especially in southern China.

L. F. Welch asked if there is any use of N on soybeans in the P.R.C.

Qu Ning-kang said that some N is applied where organic matter is very low.

Sun Huan added that N also is needed for early growth where soils are cool at planting and nodulation is slow.

L. F. Welch said that a small amount of fertilizer N is applied at planting in some states. Nodulation in Illinois is usually rapid, however, and N is not normally used.

Qu Ning-kang said that K application has given yield increases in the P.R.C., but a full report of this phenomenon has not been made.

L. F. Welch stated that in both the P.R.C. and U.S., northern soils are more

fertile and less weathered than those in the south. This is reflected in K-supplying capacity and the organic matter and cation exchange capacity.

Ma Rhu-hwa asked if K is used for soybeans grown in Canada and the northern U.S.

L. F. Welch said that soybeans are not extensively grown in Canada. The natural K levels in Illinois soils decline from north to south. More K will be used as cropping continues.

Qu Ning-kang said soil K is lower in southern China; where rainfall is higher, soils are more weathered and cropping is more intense.

E. Nafziger asked if any micronutrients are supplied to soybeans in China.

Qu Ning-kang said that molybdenum (Mo) is added.

L. F. Welch said that there is little micronutrient application in Illinois, though some Fe is applied where soil is about pH 7. Liming generally increases Mo availability.

Sun Huan stated that trace elements are seldom used in Northeast China. Mo is used occasionally.

D. A. Holt said that there seems to be no N response with soybeans in Illinois, but there is some response in Northeast China, where the season is shorter. He then asked if any research on N use been done farther north in the U.S.

L. F. Welch replied that use has increased soybean yields in some Minnesota studies. However, results have been erratic, and yield increases have not been frequent. Most increases have been found with late-season (foliar) N application.

Physiology and Genetics Working Group Session

Convener: John S. Boyer
Reporter: Archie R. Portis

Interactions of Carbon and Nitrogen Metabolism in Crop Productivity

RICHARD H. HAGEMAN

The high carbohydrate content of maize grain (80% carbohydrates versus 1.5% nitrogen) dictates a predominant role for photosynthesis in achieving maximum yields. However, the metabolisms of carbon (C) and nitrogen (N) are closely linked, and enhanced use of fertilizer N is so closely associated with increased maize yields (Hageman, 1979) that both C and N metabolism should be considered when attempting to identify factors that limit productivity. In Evans' book (1975) only the chapter on rice accords a major role for N as a limiting yield factor (Murata and Matsushima, 1975). This preoccupation with photosynthesis as the primary limiting factor of yield again is indicated by Johnson (1982). Shading, defoliation, and canopy studies usually are interpreted with respect to the effect on photosynthesis, and little attention is given to such treatments on nitrate assimilation, although it is known that light affects nitrate reduction in leaves.

For rice, high yields are possible only under high N, and plant characteristics that confer high yielding ability often are associated with responsiveness to N (Murata and Matsushima, 1975). These authors and Yoshida (1972) indicate that N has two major roles: the establishment of the yield capacity and establishment and maintainence of photosynthetic capacity. The work of Morita (1980) shows that 90% of the N lost from the leaves during normal senescence was from the chloroplasts.

For soybeans, Sinclair and deWit (1976) suggested that it is the loss of N from vegetation in support of grain development that was responsible for "self-destruction." Wittenbach et al. (1980) showed that the loss of N from soybean leaves of field-grown plants was concurrent with changes in chloroplast structure and loss of photosynthetic activity during grain filling.

For certain cereals, Stoy, as quoted by Mengel and Kirkby (1979), noted that an adequate N supply during early growth stages was important in determining the number of ears per unit of area. For tomatoes, a deficiency of N but not carbohydrate repressed megaspore development while the reverse was true for microspore development. Tollenaar (1977) has suggested that ear size may frequently limit crop yields.

Little information is available for maize on the physiological processes that determine ear and kernel initiation (Duncan, 1975). However, Krantz and Chandler (1954) noted that increasing the soil N level from deficient to sufficient increased grain weight three or four times more than stover weight. The occurrence of barren plants commonly is associated with an inadequate N supply. Decrease in leaf N of maize during the grain-filling period was concurrent with the loss of chlorophyll (Christensen et al., 1981).

The role of N in achieving high productivity of other crops appears similar to the two roles proposed for rice. A third role for N as a factor limiting maize yields can be inferred from the work of Tsai et al. (1978). They suggested that protein accumulation in the kernel could be a factor in regulating kernel development. With five maize hybrids, Below et al. (1981) found that the capacity of the plant to supply N to the ear was limited more than the capacity to provide photosynthate. One of the five hybrids showed a decrease in the rate of accumulation of N by the ear at 30 to 33 days after anthesis. While this does not prove a need for concurrent accumulation of N and dry weight by the kernels, it may indicate a potential limitation in availability of N. Possible needs for continued N acquisition by the kernel would be to permit adequate and normal embryo development which could affect hormone balance, and maintain the enzyme and enzyme systems needed for deposition of starches and proteins and energy generation.

We investigated the interaction of C and N metabolism in relation to maize

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productivity. Some of the results obtained are summarized.

Changes in dry weights, reduced N, nitrate, and nitrate reductase activity of above-ground plant parts (stover) and ears of field-grown maize were measured at intervals between anthesis and grain maturity. Nonstructural carbohydrate contents also were measured in some instances. Changes in dry weight and reduced N content were used to approximate net *in situ* photosynthetic and nitrate assimilation activities and determine whether the availability of photosynthate or reduced N was limiting grain production.

All five of the hybrids studied showed extensive remobilization (loss) of reduced N from the stover during grain development. This loss was initiated by 18 to 21 days after anthesis. About 70% of this N loss was from leaves. In contrast, three of the five hybrids had more vegetative dry weight at grain maturity than at anthesis, while the loss of stover dry weight by the other two hybrids was negligible. By 42 days after anthesis, when the bulk of the ear weight had been acquired, the average gain in stover dry weight for the five hybrids was 12% while the loss of stover-reduced N was 28%. Where measured, the increase in stover dry weight was due largely to deposition of carbohydrates in the stalk. Thus, photosynthetic capacity was adequate while nitrate reduction capacity was inadequate for ear demands. The changes in rate of accumulation of dry weight and carbohydrate (where measured) accumulation in the vegetation during the first 42 days after anthesis imply that the rate of supply of photosynthate to the ear was probably not a limiting factor for any of the five hybrids.

The maximum remobilization of stover N during grain development was 1.8 g N plant^{-1} for the genotypes examined, while the amount of reduced N accumulation by the grain varied from 1 to 5 g N plant^{-1}. The amount of newly reduced N (nitrate reduced after anthesis) provided from 48% to 72% of the total N accumulated by the ear. The relative amounts of newly reduced N and remobilized N vary with genotype and environment. With respect to insuring high productivity, there is more flexibility in the system (genotype and environment) for increasing the supply of newly reduced N than in enhancing the remobilization of vegetative N.

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DISCUSSION

Wang Jin-ling asked about U.S. studies of the effects of foliar application of nitrogen.

R. H. Hageman stated that such studies have not been successful, although some people report foliar application to be beneficial. He mentioned the studies of Smith in the 1960's which showed that the application of urea to wheat resulted in increased protein content but reduced bread quality. In earlier studies, Hageman found that neither nitrate or urea applied to maize or soybeans resulted in increased protein content or yield. In recent studies by Hanway in Iowa and Vasilas in Maryland, increases in yield were reported with soybeans. Studies at Urbana were not successful. Hageman mentioned that he has a study under way on the effects of urea on maize yield. He stated that it was logical that urea should increase maize yields, but mentioned that studies of Ed Deckard suggest that the nitrogen content of maize was limited to about 3%. Hageman therefore wondered if the nitrogen supplied by application of urea to maize was translocated out of the leaf to the stalk where it would not be used.

Wang Jin-ling mentioned that foliar application of urea to soybeans has been conducted on a large scale in China with a 3-5% yield increase. The urea was applied in a liquid form at 8 kg/ha by airplane to large areas in full flowering stage, with no leaf burning.

Soybean Photosynthesis

WILLIAM L. OGREN

Photosynthesis is a major limiting factor in soybean yield production. This has been demonstrated by CO_2 enrichment, which increases photosynthesis, and by various environmental conditions which reduce photosynthesis, such as shading, lodging, water stress, and removal of large numbers of leaves experimentally or by insects and pathogens. The two concepts to consider in increasing photosynthesis are the instantaneous photosynthesis rate and the duration of the pod-filling period (Ogren, 1978). Duration of the pod-filling period is determined by the growth and developmental pattern of the soybean canopy, and primarily is a function of the rates of canopy closure and leaf senescence. Instantaneous photosynthesis rate is determined by the biochemical efficiency of the CO_2 assimilating process, and is the major research interest of our laboratory.

Large differences in soybean leaf photosynthesis, expressed per unit of leaf area, have been reported and suggest that photosynthetic productivity might be increased through breeding. However, if photosynthesis rates are calculated on leaf weight basis, differences between cultivars are small (Ogren, 1976a). Thus there are no large genetic differences in photosynthetic efficiency, but the reported variation is due to genetic variations in the amount of photosynthetic machinery per unit of leaf area, that is, differences in leaf thickness (Ogren, 1976a; Ogren, 1976b). While these differences are significant in single leaf measurements where the rate is a function of the amount of leaf material, they are not very significant in canopy photosynthesis where the amount of leaf material is in excess and the rate is determined by the amount of light available. Thus to increase soybean photosynthetic efficiency it will be necessary to create improved genetic material.

Analysis of soybean photosynthesis suggested that two primary limiting factors were the specific activity of the carboxylating enzyme, ribulose bisphosphate carboxylase/oxygenase (Rubisco), and photorespiration (Ogren, 1976b; Ogren, 1978). Both are caused by constraints imposed by the kinetic characteristics of Rubisco. This enzyme catalyzes the first step both in photosynthesis (carboxylation) and in photorespiration (oxygenation). Photosynthetic efficiency can be increased if either the activity of this enzyme or the ratio of carboxylation to oxygenation can be increased. Using procedures of induced mutation, we have been attempting to genetically alter Rubisco so that carboxylation efficiency is increased (Somerville and Ogren, 1982; Spreitzer et al., 1981). Because of the large size of the soybean plant and the length of its life cycle, these experiments are being conducted with model organisms more suited to rapid genetic analysis. The plants being used are the C_3 crucifer *Arabidopsis thaliana* and the unicellular green alga *Chlamydomonas reinhardii*.

In *Arabidopsis*, several mutant strains have been recovered with lesions in enzymes of the photorespiratory pathway (Somerville and Ogren, 1982). These mutants grew normally in 1% CO_2, where photorespiration is suppressed, but died when placed in air, where RuBP oxygenation occurs and photorespiratory carbon or nitrogen accumulates to lethal levels. The mutant strains were used to select for second-site revertants which survive in air. Such revertants would survive because they possessed little or no RuBP oxygenase activity, and show increased rates of RuBP carboxylation and photosynthesis. *Chlamydomonas* mutant strains have been isolated which possess defective Rubisco and are unable to photosynthesize. Revertants were found in which the Rubisco activity has been restored, and the revertant enzyme

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analyzed to determine whether the carboxylase/oxygenase ratio or the specific activity has been altered (Spreitzer et al., 1982). Although revertants have been recovered, normal wild type activity was restored in all cases.

In conclusion, soybean yield can be improved by increasing photosynthetic productivity. This can be accomplished by increasing the instantaneous photosynthesis rate or the length of the pod-filling period. Our analysis of the instantaneous rate differences in various soybean cultivars indicates that natural genetic variability is quite small, and that major improvements will require the creation of genetic variability by unconventional techniques such as induced mutation or direct modification of the Rubisco genes. Our attempts to increase photosynthesis by induced mutation have led to techniques which apply the selection pressure necessary to achieve the desired changes, but they have not yet produced strains with increased photosynthetic productivity.

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DISCUSSION

Wang Jin-ling asked if there were any positive results in Ogren's attempts to eliminate photorespiration.

W. L. Ogren stated that all his studies were negative but that differences do exist in nature in the enzymes of widely different organisms.

Wang Jin-ling asked whether differences in leaf shape would alter photosynthesis in the canopy.

W. L. Ogren said no, because experiments at Urbana showed that isolines of soybeans with narrow and broad leaf shapes yielded the same.

Wang Jin-ling asked if pyramid-shaped plants would have been better.

W. L. Ogren replied that as long as all the light is absorbed in the canopy, the shape of the canopy was not significant with respect to photosynthesis.

J. S. Boyer asked about the results of any similar experiments in China.

Wang Jin-ling said that they found most of the soybean types with a "better" canopy structure had a higher yield.

J. S. Boyer asked if the number of plants per hectare was the same in these studies and asked about the leaf shape or orientation and pigment composition.

Wang Jin-ling replied that the canopies were closed but that there have been systematic studies on the other aspects.

Gai Jun-yi asked about the genetic variability in pod filling and senescence.

W. L. Ogren mentioned that scientists are beginning to study leaf senescence but that he was not aware of any work on genetic variation.

J. S. Boyer mentioned studies on a soybean mutant by agronomists at the University of California at Davis where apparent increases in yield per plant were obtained. The mutant had a longer retention of leaves after pod maturation but had not been studied on a field production basis.

R. H. Hageman mentioned that maize cultivars vary widely in leaf senescence in relation to kernel development.

In response to a question by J. S. Boyer on yields, R. H. Hageman said that he did not have much experience with them. Hageman concluded that increasing the duration of canopy leaf photosynthesis was an important problem.

Zhang Rong-xian asked about the importance of partitioning for increasing yield.

W. L. Ogren thought that it could be of some importance but was not as important as extending the duration of canopy photosynthesis or reducing photorespiration. Ogren mentioned that there is a rather distinct division between vegetative growth and reproductive growth in soybeans that reduces competition. He felt that there was not much of a case to be made for altering harvest index.

Zhang Rong-xian asked about any ideas for ideotypes for use by plant breeders.

W. L. Ogren commented on studies by various groups on the variation of the specific activity of RuBPase in leaves. However, he did not think that this would be useful for plant breeders.

Sun Huan asked about the reasoning behind the choices of the cultivar used to compare leaf photosynthesis and yield that Ogren had presented.

W. L. Ogren stated that the experiments were performed by Shibles in Iowa and that he did not know.

Gai Jun-yi asked if there was an optimum level for canopy development.

W. L. Ogren believed you needed to establish the canopy as quickly as possible and then switch to flowers and that this is the reason narrow-row cultivars have been useful.

Gai Jun-yi asked about the rate of pod development and growth stage. Ogren discussed the problem of breaking the apparently close relationship between flowering and leaf senescence.

Zhang Rhong-xian asked about the role of the RuBP carboxylase small subunits in determining the specific activity.

W. L. Ogren said that not much is known but that the bacterial enzyme, without the small subunits, has a higher specific activity but a much greater RuBP oxygenase activity. It is conceivable that the small subunits in the higher plant enzymes influenced the activity and CO_2/O_2 specificity of the enzyme, but the function of the subunits currently is unknown.

Inheritance and Breeding for Higher Photosynthesis Rate in Soybeans

YEE CHIEN CHANG AND JIAN LI

Eighty years have passed since Mendel's law was rediscovered and modern plant breeding commenced. When photorespiration and the C_4 cycle of CO_2 fixation were discovered in 1965, a new research domain opened. Significant yield increases through further crop management improvement are not likely. However, there is great potential for yield increase through improved utilization of sunlight. At present, 2-3% of the sunlight is utilized in a high-yielding field. It has been proved that utilization efficiency might increase to 4-5%, or even 6-8%. This can be achieved through breeding. Scientists in Japan and the U.S. consider the breeding of photosynthetically efficient plants an important area of study. Now, plant breeders in China are studying the problem in maize, rice, wheat, and other crops.

Scientists have not yet combined the recent achievements in theoretical research on photosynthetic physiology with morphology, and advances in breeding for more efficient plant morphology should combine morphology with function in breeding programs to obtain new, higher-yielding cultivars.

Soybean cultivars differ greatly in photosynthetic capacity. These differences are genetic and are independent of the environment.

In our efforts to use this variation more effectively and find a genetic basis for breeding photosynthetically efficient plants, we studied the photosynthetic rate characteristics of a cross which combined a high and low photosynthetic rate line. Because directly measuring photosynthesis with instruments is difficult and rates are affected by environmental conditions, we used an indirect index, specific leaf weight (SLW). A positive correlation has been found between rate of leaf photosynthesis and RuDP carboxylase activity. Leaf thickness and specific leaf weight are also related to RuDP carboxylase activity.

MATERIALS AND METHODS

Experiment 1

In an experiment involving 16 soybean cultivars, we investigated the dynamics of SLW from different parts of the canopy throughout the growing period. Leaves from the same position (co-growing nodes) were sampled, the leaf area measured, and dry weight recorded. Samples were collected from each co-growing node weekly from July 8 to September 11.

Experiments 2 and 3

In 1976, two lines known to differ in photosynthetic capacity were crossed in the field at Tieling. F_1 plants for producing F_2 populations were grown in the winter nursery in Hainan Island. The same cross was made in 1977, and half of the hybrid seed was grown in the winter nursery in Hainan Island that same year. All entries involving P_1, P_2, F_1, F_2, F_3, and F_4 generations were obtained in 1978. Samples from the six lines were collected from the middle leaflet of the 4th trifoliolate at the seedling stage, from the middle leaflet of the 4th, 6th, and 8th trifoliolate at flowering, and the first, 2nd, 3rd, and 4th trifoliolate from top to bottom. We feel that these leaves are representative of the various growth stages. A genetic analysis of the SLW was carried out.

RESULTS AND DISCUSSION

Dynamics of SLW

The SLW of various cultivars is summarized in Table 1. The SLW of both Liaonong 2 and Shennong 25104 is greater than that of Shi

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Shen Chang Ye, a Japanese cultivar with one of the highest photosynthetic capacities in the world. There is considerable difference between the SLW of the two sublines Shennong 25104 and Shennong 252. Cultivar selection is very important.

Inheritance of Higher Photosynthetic Capacity

SLW data measured at flowering and pod-fill show that a considerable number of F_2, F_3, and F_4 individuals surpassed the high parent. From 588 individuals at flowering, 3.4% of the F_3 and 0.8% of the F_4 plants surpassed the high parent.

There are bright prospects for using SLW as an indirect index measuring photosynthetic capacity in late generations. In addition, there can be a great difference in SLW during the growth stages (Table 2). The SLW of 7601-2-21, 7601-2-22, and 7601-7-100 is larger at pod-filling than during the seedling stage. For 7601-8-131, the SLW is larger at the seedling stage than during flowering and pod-fill. In some lines (7601-7-96) the SLW is constant throughout the growth period. The selection for high photosynthetic rate should be conducted during flowering and pod-fill since yield is determined, to a considerable degree, by the physiology of leaves during these stages.

Estimates of Heritability

Analyzing the data from experiments on heritability of various crops conducted over several decades, we find differences based on location and year. We sowed the same entries under uniform conditions in one location. We were able to eliminate environmental variation by evaluating results for three years (1976 to 1978). The data are presented Figures 1 and 2, and the results summarized in Tables 3 and 4.

There were a considerable number of individuals from F_2, F_3, and F_4 populations that surpassed the parents. A small number of genes control photosynthetic characteristics. As hybrid generations progress, the heritability increases. Therefore, it is better to select for high photosynthetic rate from the F_4 population.

Discussion of Breeding for Higher Photosynthetic Rate

The conventional breeding system which uses yield to select higher-yielding cultivars has been successful. However, photosynthesis should be applied to breeding to breed faster and more efficiently.

Some scientists believe that photosynthetic capacity decreased during the evolution from wild species to modern cultivars and that the yield improvement came from adaptation to environment. Improvement of some traits was related to decline of others, and this relationship had to be broken in order to breed for higher photosynthetic rates. Some scientists believe that photosynthetic apparatus is a complex, polygenic system and that selecting by higher yields does not automatically create new cultivars with enhanced photosynthetic activities.

Most modern soybean cultivars developed by artificial selection have a higher photosynthetic intensity (Table 5). Breeding for higher photosynthetic rate alone may be too narrow. Other traits to be considered are morphology, adaptability, productivity, disease resistance, and seed quality. It is necessary to select the agronomic parents best adapted to local conditions. When we design an ideocultivar, morphology and function must be considered. We believe that we can develop new soybean cultivars that will utilize more than 3% sunlight and yield more than 4,500 kg/ha without changing C_3 metabolism to C_4.

Table 1. SLW from different canopies of various cultivars (mg cm^{-2})

Cultivars	Leaf number (from top to bottom)							Mean values ($M \pm S_d$)	Coefficient of variation (%)	Range of variation
	1	2	3	4	5	6	7			
Liaonong 2	5.92	6.27	5.74	5.45	5.31			5.74 ± 1.46	29.65	3.68- 9.41
Shennong 25104	5.55	4.95	5.20	5.15	4.98	5.78	5.60	5.32 ± 0.71	22.71	3.31- 8.35
Shi Shen Chang Ye	4.35	4.70	5.91	4.98	5.43			5.25 ± 1.15	32.28	2.62-10.20
Tie fen 18	4.89	4.78	5.58	6.11	6.26	4.64	4.26	5.22 ± 1.07	32.82	2.95- 9.90
Kai Yu 8	5.17	4.96	4.66	4.77	4.71	4.49		4.79 ± 0.63	13.19	2.75- 7.00
Shennong 252	4.34	4.30	4.43	4.68	4.48	4.10	4.32	4.38 ± 1.16	26.41	2.22- 7.08

Table 2. Dynamics of SLW in various stages of different lines (mg cm^{-2})

Lines	Stages										
	Seedling (June 18)	Flowering (July 13)	Pod filling (August 19)								
7601-2-21	3.94	4.98	5.71 (2)	6.61 (1)	7.38 (1)	7.85 (1)	8.92 (2)	9.09 (3)			13.22 (1)
7601-2-22	3.88	3.80		6.61 (2)	7.38 (1)	7.85 (2)	8.19 (3)	9.09 (2)	10.74 (1)		13.22 (1)
7601-7-100	3.87	5.51		7.02 (3)	7.74 (1)	7.85 (3)	8.26 (2)	9.50 (2)		11.15 (1)	
7601-8-131	5.08	5.38	4.95 (1)	5.78 (1)	6.19 (2)	6.61 (3)	7.02 (3)	6.77 (2)			
7601-5-43	3.68	4.95		5.78 (1)	6.19 (3)	6.61 (1)	7.02 (1)	7.62 (2)	7.38 (1)	7.85 (1)	
7601-7-96	5.26	5.23	7.02 (2)	7.74 (1)	7.85 (2)	8.62 (2)	9.50 (1)	10.33 (2)	10.74 (1)	11.57 (1)	

Figures in ( ) refer to leaf number from top to bottom.

Table 3. Estimates of heritability of SLW of Shennong 7601 (flowering stage)

Source of variation	d.f.	M.S.	Variance	Covariance	Heritability (%)
P_1	9	4.564	0.507		$h^2 = \frac{V_{F_2} - 1/2(V_{P_1} + V_{P_2})}{V_{F_2}}$
P_2	6	1.612	0.268		$= 0.1818$
F_1	11	8.224	0.747		$h^2_{F_{43}} = \frac{S(x - \bar{x})(y - \bar{y})}{S(x - \bar{x})^2}$
F_2	28	13.247	0.473		
F_3	588	322.290	0.548		$= \frac{273.59}{322.29} = 0.8489$
F_4	588	254.690	0.433	273.59	

Table 4. Estimates of heritability of SLW of Shennong 7601 (pod filling stage)

Source of variation	d.f.	M.S.	Variance	Covariance	Heritability (%)
P_1	10	12.774	1.2774		$h^2 = \frac{V_{F_2} - V_E}{V_{F_2}}$
P_2	26	22.464	0.8640		$= 0.4363$
F_1					$h^2_{F_{43}} = \frac{S(x - \bar{x})(y - \bar{y})}{S(x - \bar{x})^2}$
F_2	43	81.562	1.8970		
F_3	340	296.150	0.8710		$= 1.2973$
F_4	340	537.490	1.5810	384.19	

Table 5. Photosynthetic rate of various varieties (mg Co_2 dm^{-2} hr^{-1})

	Low fertility				High fertility			
	4th leaf		Top leaf		4th leaf		Top leaf	
	Photo. rate	Coefficient of variation (%)	Photo. rate	Coefficient of variation (%)	Photo. rate	Coefficient of variation (%)	Photo. rate	Coefficient of variation (%)
Pennen	24.3	32.2	32.8	9.4	29.0	15.1	38.5	22.0
Eolie	25.5	20.8	37.2	22.2	26.9	12.3	33.0	11.4
Bai Whai Shou 1	22.2	13.1	36.7	20.9	26.3	21.2	34.0	18.3
Norin 1	21.0	24.9	30.3	9.8	24.5	13.3	34.2	7.0
Norin 2	27.1	10.5	34.3	9.7	29.6	8.0	30.9	12.7
"Manchu"	22.7	17.3	33.4	12.7	26.7	11.3	32.6	9.0
Lilimnin	27.6	20.3	30.9	3.9	25.1	12.8	28.8	10.7
Chiao	26.6	8.7	33.9	14.5	25.7	8.2	40.4	12.9
Ashuiu	25.7	16.5	30.4	8.9	30.1	15.8	36.2	26.1
Chulion	27.5	27.0	32.3	13.9	27.9	20.8	32.8	8.1
Yuyu	27.1	15.9	33.8	9.2	23.3	18.5	35.5	12.3
Harosoy	28.8	20.8	45.2	7.1	32.3	21.4	39.5	10.6
Mandarin (Ottawa)	31.3	19.6	37.1	11.1	31.2	28.4	36.8	7.3
Kent	26.9	7.1	42.2	9.8	31.3	14.3	36.1	14.7
Lincoln	25.9	10.7	35.9	18.0	26.1	12.0	32.4	7.1
Semiwild	28.9	21.7	24.8	6.4	31.0	21.8	25.0	33.0
Wild sp.	23.7	27.4	26.3	21.0	27.5	23.7	27.2	18.2
Mean	26.2	10.0	33.8	13.5	27.9	9.7	34.1	12.5

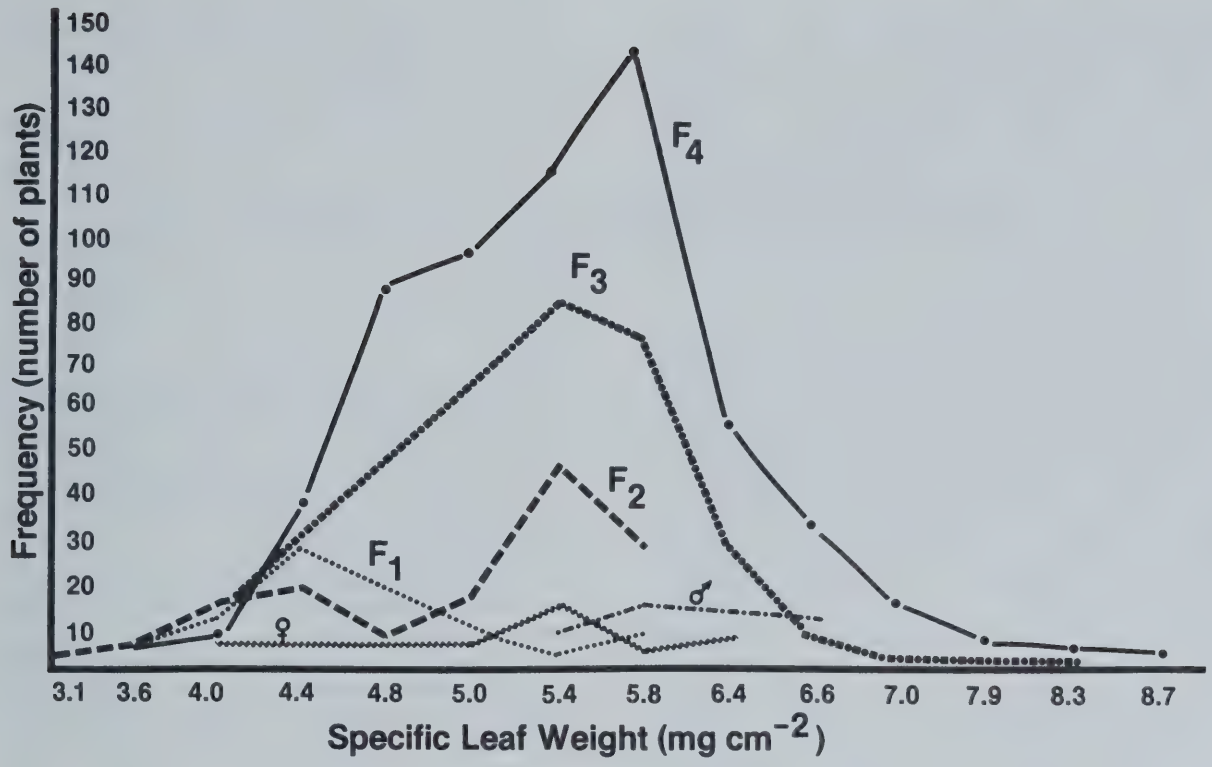

Figure 1. Distribution of specific leaf weight of Shennong 7601 (1) during flowering, Tieling, 1978.

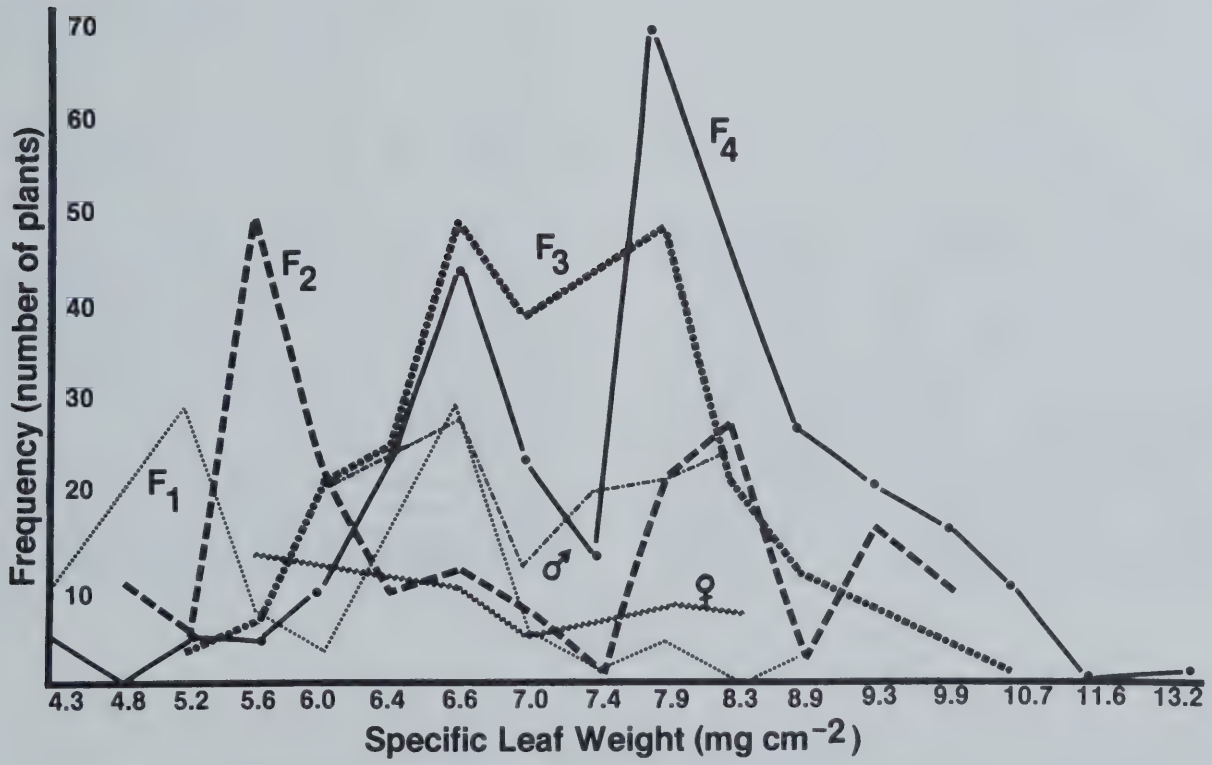

Figure 2. Distribution of specific leaf weight of Shennong 7601 (2) during pod filling, Tieling, 1978.

Plant Tissue Culture and Agriculture

JACK M. WIDHOLM

Plant tissue cultures are useful in basic studies of plant biology and for manipulating plants genetically. Recent scientific advances have created a new field called "genetic engineering," which can be defined as genetic modification using unconventional techniques such as embryo, anther, protoplast, or tissue culture methods or isolated deoxyribonucleic acid (DNA), chromosomes, organelles, viruses, or microorganisms as vectors.

The use of these techniques could bring about advances in crop improvement by affecting productivity, quality, and efficiency. Possible manipulations include increasing photosynthesis and nitrogen fixation, introducing nitrogen fixation to nonlegumes, increasing nutritional quality, and introducing disease, insect, herbicide, cold, heat, drouth, and salt tolerance. Most of these manipulations have not been accomplished with plants because all of the techniques needed, namely genetic transformation, correct gene isolation and control, selection, protoplast formation, and subsequent plant regeneration, have not been perfected. Basic research is needed to develop these methods and to understand the processes which need to be modified to improve plants. This research effort is especially important to the universities since this is the kind of work that we should be doing.

To date tissue culture methods have been used successfully for mass plant propagation, to rid vegetatively propagated plants of viruses, to rescue embryos in incompatible crosses, to produce commercially used varieties from anther culture, and to produce useful variation in regenerated plants. We can look for greater achievements in the future since more resources are being focused on this area.

DISCUSSION

D. M. Daugherty asked about the treatments that were required to obtain regeneration.

J. M. Widholm said that usually lowering the auxin concentration, raising the cytokinin level, and placing the tissue under light was sufficient.

D. M. Daugherty asked if that meant we do not know what to do to get regeneration for the other cases.

J. M. Widholm said that this was true, but that procedures for ten or more new species are reported each year. These usually involve the use of subtle modifications or the use of tissue of the proper origin.

Shong-Wan Norby asked about the differences between the cells in culture and normal plant cells.

J. M. Widholm said that there are physiological differences. Widholm mentioned as an example that efforts to select for herbicide resistance should be done on cells that are green and grown photosynthetically in culture, although usually cultured cells are not green. He also said that many aspects of plants have to do with differentiation, and therefore cultured cells may differ dramatically from the plant cells. As one striking example of this phenomenon, Widholm stated that tobacco plants regenerated from cells resistant to 5-MT (5-methyltryptophan, a tryptophan analog) were not resistant, even though the cells from the regenerated plant were resistant when introduced back into a culture system.

D. M. Daugherty asked if embryo tissue was better in those cases where getting regeneration was difficult.

J. M. Widholm said that this was true in some cases, one example being maize.

J. M. Widholm is professor of plant physiology, UIUC.

However, the developmental stage was also very important. He mentioned also that many cultivars of maize will regenerate, while others do not and that regeneration was believed to be controlled by one gene. However, regeneration has not been obtained at all with soybeans.

R. H. Hageman discussed some of the studies on maize at the University of Illinois at Urbana-Champaign extending over the last 80 years as another obvious but slow way of "doing" genetic engineering. Over this period the crude protein in the grain has been increased from 9% to 25% and also decreased from 9% to 5% by breeding techniques, illustrating the considerable variability in the genetic components of the plant. The same thing has been done with both increasing and decreasing the oil content. He also pointed out that this approach was not limited to metabolites, as exemplified by recent studies in his laboratory selecting for leaf nitrate reductase levels. They have obtained a two-fold difference after only six cycles. Hageman mentioned that the variation in both metabolite and enzyme levels does affect other characteristics of the plant and gave some examples. Finally Hageman emphasized that this approach, while slow, did not require sophisticated techniques but only careful consideration of where and how to select for this plasticity in the genotypes.

J. M. Widholm then talked about the fact that polygenic traits were likely to be more suitable for classical breeding approaches, while single gene traits, if expressed, were better for cell culture techniques. He mentioned some advantages opened up by cell culture, including the ability to screen large quantities of material, the ability to fuse cells and mix genes of otherwise incompatible species, and the ability to mix cytoplasmic components that otherwise are maternally inherited. Widholm stated that he hoped that these new techniques would prove to be of considerable importance, although this certainly remains to be seen.

CONCLUDING DISCUSSION TO THE PHYSIOLOGY AND GENETICS WORKING GROUP SESSION

Wang Jin-ling expressed the view that genetic engineering techniques have great prospects, but that we were only at the first stage in their development. Therefore for the near future, conventional breeding techniques must not be abandoned, as a considerable variation already exists in nature sufficient to achieve many of the desired goals.

J. S. Boyer commented that most scientists would probably agree. He pointed out that genetic engineering techniques need to be nourished in addition to maintaining support for the "tried and true" methods, since these techniques have great promise for allowing alterations that might otherwise require a very long time.

Wang Jin-ling then mentioned two areas, tree propagation and virus resistant potatoes, where these techniques are currently being utilized in China.

J. S. Boyer concluded the session with the comment that it was apparent that thoughts about the application of tissue culture and genetic engineering techniques to agricultural problems are similar in both countries.

Plant Protection Working Group Session

Convener: Sung M. Lim

Reporters: Dale I. Edwards
and Gregory R. Noel

An Overview of the Epidemiology of Selected Fungal, Nematode, and Seedborne Pathogens of Soybeans

RICHARD E. FORD

Plant disease epidemiology is the study of development of a virulent pathogen in a susceptible host. Modern computer technology has helped us envision how minor changes in factors affecting pathogen growth can cause marked crop losses due to disease.

Plant pathologists have studied the epidemiology of many soybean diseases using the history of cropping practices, weather, and epidemics. They have developed soybean disease risk maps that can help farmers decide which cultivars to plant and which practices to follow. All of this research eventually contributes to an integrated pest management (IPM) system, in which chemical, physical, and cultural pest control practices are coordinated.

Transmission of viruses, bacteria, and fungi by seed often is the most important step for an epidemic to become established. The disease cycle is assured of starting in each new planting season with inoculum from infected or infested soybean seeds. The 0.1-5.0% incidence of embryo infection by soybean mosaic virus (SMV) closely parallels that of recorded seed transmission. Seed coats of immature seeds can contain large quantities of virus, but transmission rate can vary according to cultivar. Genetically different Amsoy and Mukden cultivars transmit SMV at high and low rates, respectively.

Pod and stem blight, caused by *Phomopsis* spp., is an ubiquitous fungal pathogen of soybeans and is aided in its survival and transmission by being seedborne. How this fungus infects tissues, remains latent, and eventually is expressed needs further study. Disease incidence has a low positive correlation with temperature and a high positive correlation with rainfall and relative humidity during pod-fill.

Soybean mosaic virus increases a plant's susceptibility to *Phomopsis* seed decay. Some *Phomopsis* and *Colletotrichum* species isolated from weeds are more pathogenic than those isolated from soybeans. Other interactions are under investigation, including fungal and yeast infections of seed associated with insect-feeding damage.

Treatment of seeds with bactericides, fungicides, or biological control agents is currently recommended for fields being grown for seed production in the temperate regions and for production fields in the subtropical regions. The economic advantages of fungicide applications to control soybean diseases require continuous study.

Phytophthora megasperma f. sp. *glycinea* causes a severe root rot when oospore inoculum levels are high. Infection alters the internal water status in plants. Flooding, low temperature, and the use of the herbicide Treflan increase the probability of a disease epidemic. Disease-suppressive soils are being studied to determine potential biological control mechanisms (bacteria or other fungi) antagonistic to the pathogen under natural growing conditions.

Foliar diseases of soybeans cause significant yield reductions under conditions we consider normal, not epidemic. Most of these diseases are held in check by general resistance. Our research stresses individual diseases plus interactions with other diseases such as brown spot caused by *Septoria glycines*, pustule caused by *Xanthomonas phaseoli* pv. *sojensis*, and stunting caused by the soybean cyst nematode, *Heterodera glycines*. Disease risk is monitored regularly to enable any shift in pathogen populations to be detected. Severity ratings of brown spot disease at the R5 to R6 growth stages correlated significantly with percentage of yield reduction.

Soybean cyst nematode is a major factor limiting soybean yields in Illinois. It has spread slowly but now has reached Illinois's northern border. The soybean cyst nematode exists in large numbers in infested soils in the southern half of the state, and epidemics have occurred there as well as in other areas where susceptible soybean cultivars are grown. Yield losses can be prevented by long-term rotations with maize or other

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nonsusceptible crops--four or five years between soybean crops. Most farmers are not willing to wait that long, so they plant seed mixtures of susceptible:resistant cultivars for effective control. The damage threshold in Illinois is 60-100 eggs and larvae/250 cm^3 soil sampled at planting, and the economic injury level is 300-500 eggs and larvae/250 cm^3 soil. Severe yield losses can be prevented by following recommended cropping practices and rotations. Resistance is the next line of defense. Effective nematicides are not economical except in soils infested with high populations where banding or furrow treatments can be used.

DISCUSSION

G. R. Noel asked the Chinese scientists if races of the soybean cyst nematode (SCN) are known to occur in China.

Wang Jin-ling responded that the race concept is not known or not fully understood.

R. L. Bernard asked if resistant soybean cultivars are recommended for control of the SCN in China.

Wang Jin-ling responded that some brown- and black-seeded types have some resistance to the nematode where it causes damage in northern China. Resistance has not been developed and used as in the U.S.

Yu Zilin asked how U.S. scientists determine plant resistance for the SCN.

D. I. Edwards and G. R. Noel responded that soil is inoculated with an aqueous suspension of eggs or larvae of the SCN; or soils naturally infested with all stages of the SCN are placed in growth containers (pots 7.6 to 12.7 cm in diameter) and planted with soybean lines. The plants are evaluated approximately 30 days later for numbers of reproductive units, usually the white female stage of the SCN.

Gai Junyi asked if there is complete resistance to the SCN in the U.S. and if it is possible to obtain resistance to all races of SCN by combining different resistant sources in a single cultivar.

R. L. Bernard said that we do not have complete resistance to the SCN. The use of Peking as a resistant source has given a high degree of resistance to race 3 but it is not complete. PI 88788, another resistant source, has a lower level of resistance than Peking. The use of Peking and PI 88788, alone or in combination, has given resistance to races 3 and 4 of the SCN.

Wang Jin-ling asked why the SCN is such a serious and widespread problem in the Mississippi Valley area of the U.S.

D. I. Edwards responded that this is an area of intensified soybean production and that soybeans are cropped frequently, often every other year in rotation with maize. Such cropping practices are conducive for nematode population buildups.

Zhang Zijin asked about the availability and performance of SCN-resistant cultivars.

R. L. Bernard, using a slide belonging to D. I. Edwards, showed the available public resistant cultivars and their maturity group range. These resistant cultivars generally perform well on heavily infested land but may yield lower on noninfested land than high-yielding susceptible cultivars.

Zhang Zijin asked about nematodes other than the SCN that damage soybeans in the U.S.

G. R. Noel mentioned lesion, reniform, root-knot, sting, and lance nematodes as damaging parasites, especially in the southern U.S. Lesion nematodes are found distributed throughout the U.S. soybean producing areas.

Wang Jin-ling inquired about the distribution of pod and stem blight.

R. E. Ford said that it is endemic in most soybean areas.

S. M. Lim stated that brown spot of soybeans is the most important foliar disease of soybeans in Illinois as well as in several other states of the U.S. Yield reductions of 8% to 12% occur under natural conditions and 12% to 34% when plants are inoculated artificially. Lim said that there are no soybean cultivars highly resistant to brown spot. Because of this, R. E. Ford mentioned that the fungicide benomyl is used as a tool for determining yield reduction.

R. L. Bernard commented that the use of benomyl as the reference point for determining brown spot yield losses may not be accurate because we do not know what effect the fungicide has on the soybean plant and that perhaps the fungicide does not give the level of control as would a resistant soybean cultivar.

Wang Jin-ling mentioned that frogeye leafspot, which is caused by *Cercospora sojina*, is an important disease in northeast China.

R. L. Bernard mentioned that most of the soybean cultivars grown in the U.S. are resistant to three or four races of *C. sojina*.

Studies on the Epidemic Regulation and Control of Soybean Rust Caused by *Phakopsora pachyrhizi* Sydow

TAN YU-JUM, YU ZI-LIN, AND LIU JIA-LIN

Soybean rust, caused by *Phakopsora pachyrhizi* Sydow, is a disease epidemic in southern China and constitutes a menace to soybeans in the area. The pathogen has been reported in 16 provinces of China (Dai Fang-lan et al., 1958; Dai Fang-lan, 1979). Spring-, summer-, autumn-, or winter-sown soybeans are infected in different regions of southern China. The disease is most severe in autumn-sown soybeans, when yields may be reduced by 10% to 30%; in some areas, over 50%. Soybeans infected in the early stages of development may not yield at all.

The world soybean rust situation has been reviewed by Yang (1977) and Bromfield (1976). The etiology, epidemiology, and control measures of soybean rust have been studied by phytopathologists of many countries. The information on soybean rust in China also has been reported (Yu Zi-lin et al., 1980). We studied urediospore characteristics, main environmental factors that affect rust development, and fungicides for control of soybean rust in some of the southern provinces of China.

PATHOGEN AND MORPHOLOGY

P. pachyrhizi produces uredia and telia on soybean leaves and parasitizes hypophyllous and a few epiphyllous legumes. Mature uredia are brown or dark brown, oval or subglobose. Paraphyses are incurved and united at the base to form a dome-like structure over the uredium, the top of the uredium has a narrow lumen, and urediospores are produced within the uredium. Urediospores collected in Hubei are light brown, oval or elliptical, 20.8 to 38.4 x 14.4 to 22.4 nm with an average of 29.7 to 17.9 nm, and with echinulate hyaline walls. The telia are dark brown, dispersed and aggregated, and irregular. Teliospores are short, clavate, two to seven layers, 11.9 to 16.66 nm long and 7.1 and 7.1 to 11.9 nm wide with an average of 14.0 to 8.6 nm.

STUDIES ON GERMINATION AND PENETRATION

Urediospores of *P. pachyrhizi* were collected from freshly sporulating pustules on soybean leaves, made into a suspension, and then sprayed on the top of glass microscope slides which had been covered with 1.25% water agar. The slides were placed in 90 mm culture plates on top of moist filter paper. The culture plates with slides were incubated at 24°C. The percentage germination of 300 to 500 spores per slide was recorded using a light microscope after six hours. In addition, slides with urediospores were placed out of doors where the temperature ranged from 8.7° to 29.8°C, in a refrigerator ranging from 5° to 8°C, and at room temperature ranging from 13° to 24°C. The percentage of germination was recorded daily for five days, when germination ceased. The effect of pH on urediospore germination also was studied over a pH range of 2.2 to 10. Each experiment was conducted twice.

A study on urediospore penetration was made using the methods of Bonde et al. (1976) and Marchetti et al. (1975) on whole leaves and thin sections. Whole leaflets were harvested at 12 hours after inoculation and every 12 hours after that for up to seven days. The leaflets were fixed in absolute ethanol-acetic acid (2:1, v/v) for 48 hours, cleared in lactophenol for 48 hours, and stained with 0.1% cotton blue in lactophenol for 20 hours. For thin sections, leaflets were cut into 1- to 2-cm pieces, fixed in formaldehyde plus acetic acid (F.A.A.) for 48 hours, dehydrated in an ethanol series, imbedded in paraffin, and sectioned at 10 nm on a rotary microtome. Sectioned material was stained with safranninfast green and mounted in Canada balsam.

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EPIDEMIOLOGY AND FORECASTING

A field study was made on the relationship of disease severity to temperature and humidity. The test field was divided into small plots, each 22 m long, and replicated three times. From 1978 through 1980, autumn-sown soybeans were planted on July 7 of each year. Disease severity was recorded every three to five days based on a scale from 1 to 5 in which 1 represented below 20% and 5 represented 81-100% (see footnote a to Table 1). Average temperature and rainfall were recorded daily.

In a similar field plot, following the same experimental design, Hou-zi-mao soybeans were sown seven times at 15-day intervals. Disease severity was recorded every five days beginning with the seedling stage, using the 0 to 5 disease scale. Similar data were collected from a second experiment in the same field.

CULTIVAR RESISTANCE

Variation in resistance to soybean rust was studied. Ten cultivars with good agronomic characteristics which were considered tolerant to the pathogen were collected from different regions where rust occurs. The cultivars were planted in a plot 55 m long on July 20. There were three replications of each cultivar, with Hou-zi-mao as the susceptible check. Disease index readings were recorded 15 days before harvest.

The spread of soybean rust was studied over a seven-year period, using the disease index data and the following formula for determining the speed of spread of a disease developed by van der Plank (1963):

$$\lambda = \frac{1}{t_2 - t_1} \left(\ln \frac{x_2}{1 - x_2} - \ln \frac{x_1}{1 - x_1} \right),$$

This was correlated with ϕ (water integral index) using the formula of Schipanov (1960):

$$\phi = \left(\frac{x}{\delta_x} + \frac{y}{\delta_y} \right) \div N$$

which included for this study the data for rainfall (y) and number of rainy days (x) ($r_{\lambda\phi} = 0.946$).

Since rust does not occur with spring- and summer-sown soybeans in Hubei, the speed of spread of the disease was calculated only for the autumn-sown soybeans. Autumn is the time when the temperature for rust development and spread by air currents are optimum. Rainfall and the number of rainy days were the only two factors used for forecasting the disease severity by the regression equation. We excluded temperature, duration, and pathogenic quantity from the forecast.

CHEMICAL CONTROL

Studies were carried out in Da-tian County of Fujian Province in experimental small plots and in production fields. In the experimental plots, Da-tian cultivar was planted on August 17 in 22 m long plots and sprayed three times during the flowering period, which was between September 27 and October 5. Two fungicides were used: 75% Daconil at 1:750 and 20% Baytan at 13 µ/ml, respectively. At 15 to 20 days before maturity, 100 plants from each replication were used to determine the disease severity index: 0 = no uredia; 1 = uredia sparse and dispersed, leaf color normal; 2 = uredia well distributed, yellow halo around uredia; 3 = uredia dense, leaf yellowing; 4 = uredia dense and aggregated, leaves withering or dropped on less than one-third of the plant; 5 = leaves yellow and dropped between one-third and one-half of the plant; and 6 = leaves withered, leaf drop over two-thirds of the plant.

The field studies included 21 production teams of three production brigades in the Shan-jang commune in Da-tian County, Fujian Province. The total area of the test was 10.25 ha. Two fungicides were sprayed at the beginning of the flowering period, at full-bloom stage, and at late-flowering stage: 25% phosphorylamide at 1:250, and 75% Daconil at 1:250. Daconil also was sprayed only at full-bloom stage on 3.8 ha. Three rows of each field were not sprayed. Yields were collected from $10m^2$ in each field. A soybean rust severity index was made for each treatment as described previously.

RESULTS AND DISCUSSION

The factors that affected urediospore germination and penetration in Hubei Province were similar to those reported by other investigators (Keogh, 1974; Kitani and Inoue, 1960; Bonde et al., 1976; Marchetti et al., 1975; and Marchetti et al., 1976). Urediospores germinated within a range of 8° to 36°C with an optimum of 15° to 26°C. Germination was highest at 24°C and lowest at 30° to 36°C (1.8% at 36°C). Urediospores germinated over a pH range of 2.2 to 10.0 with an optimum pH of 5 to 6; over pH 6 or below pH 4, the germination rate decreased. Urediospores survived for 61 days at room temperature, 27 days out of doors, and 18 days at low temperatures. Germination was

higher in the dark or under dim light than in ordinary light; urediospores did not germinate under direct sunlight. The germtubes of urediospores grew away from the light, but showed no direction when grown in the dark.

Urediospore penetration took place under moist (dew) conditions in a range of 15° to 28°C and urediospore production for six to seven days at 22° to 26°C. The rate of infection decreased at 15°C and did not take place over 28°C. To become infected, plants must be kept under moist (dew) conditions for more than seven hours. The infection rate increased with time from 7 to 24 hours, with host penetration at the highest rate at 22° to 26°C. Under moist conditions at room temperature, urediospores germinated within 1 to 2 hours, with appressoria production at the tip of the germtube in 5 to 6 hours, and with a few infection hyphae penetrating the epidermis and forming a transepidermal vesicles. It took at least 7 hours for the transepidermal vesicles to penetrate the host cells and 24 hours for the production of the first uredium. Uredia matured in six to eight days. Urediospore release took place after the thirteenth day.

Environmental conditions in the field influenced disease development (Fig. 1). The daily average air temperature before September 6, 1978, was 29° to 30°C, which was unfavorable for disease development. After September 8, the daily average air temperature was below 25°C, which was favorable for disease development. However, rainfall was 9.8 mm and there were only four rainy days. No uredia were found, and 1978 was considered a year of low infection.

The daily average air temperature before August 27, 1979, was above 27°C, but there was little or no rainfall and thus it did not favor disease development. In September the average air temperature was below 27°C, the rainfall was 50.3 mm, and the number of rainy days was 12. The disease index for 1979 was 48.34, and 1979 was considered a year of intermediate disease development.

The rainfall and number of rainy days in August and September 1980 were 423.2 mm and 15, and 46.2 mm and seven, respectively. The daily average temperature for the two months, except for four days in August, was below 27°C. The disease index was 73.95, and 1980 was considered a severe disease year.

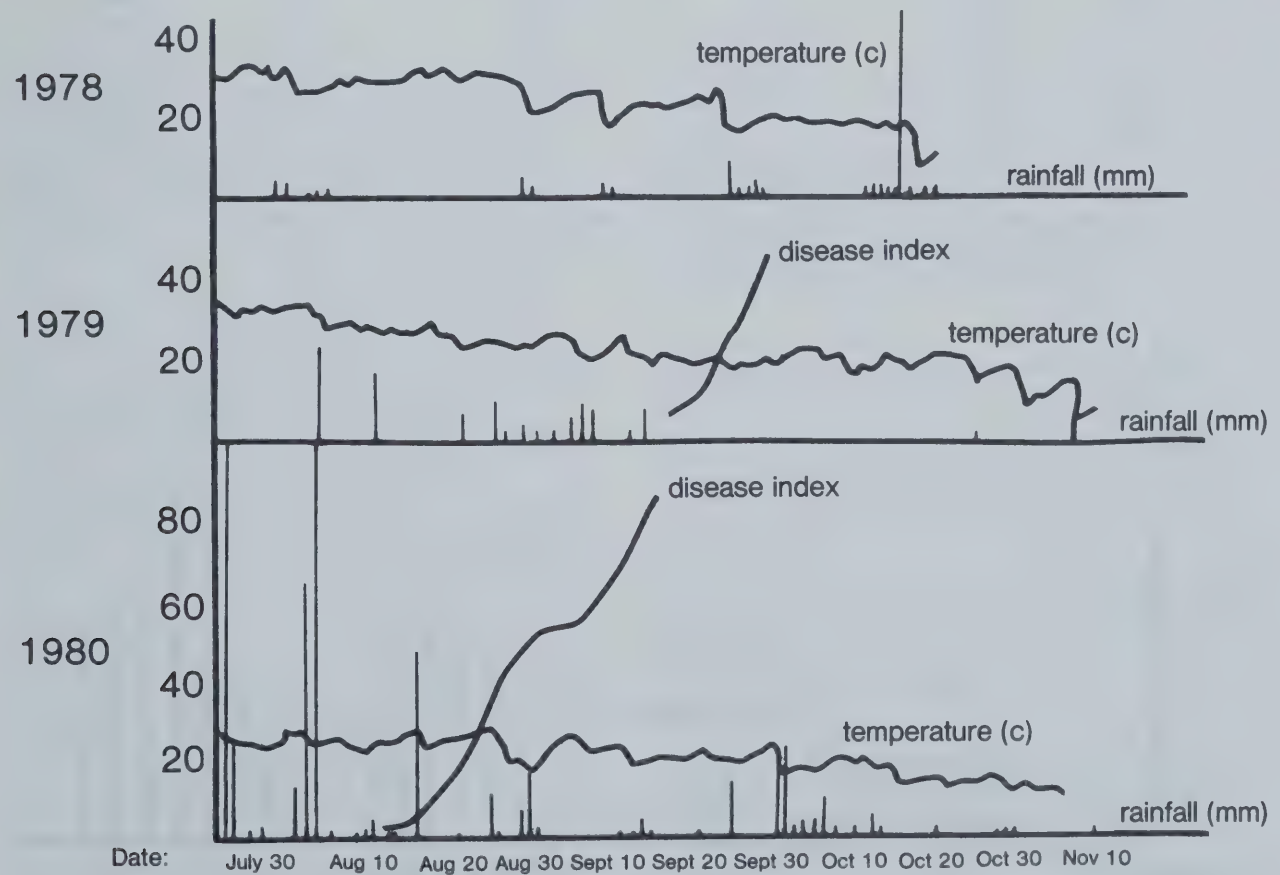

Figure 1. Relationship of disease severity with temperature and rainfall.

These results show that the average day air temperature (below 27°C), heavy rainfall, and numerous rainy days through August and September were the main factors influencing the severity of soybean rust in Hubei Province. These results agreed with those from a survey of local farmers' fields.

The data from seven years (1973 to 1979) for autumn-sown soybeans were analyzed, and a disease severity rating was calculated in which 1 = less than 20%; 2 = 21-40%; 3 = 41-60%; 4 = 61-80%; and 5 = 81-100% (Table 1). The disease severity index varied among years. General agreement was found between the disease severity index values and predicted values (Table 1).

A relationship was found between the disease severity index and growth stage. Soybean plants are more resistant to *P. pachyrhizi* during the vegetative stages than during the flowering and reproductive stages (Fig. 2). Susceptibility increased with advance in plant age until leaf fall. In the second study, the disease index was 0 in the seedling stage, 9 in the pod-formation stage, 41 in the pod-filling stage, and 73 in the mature stage.

Cultivar resistance. All ten of the cultivars tested became infected (Table 2). However, there were differences in the disease index between cultivars. Jiu-Yue-wang had the lowest disease index and was considered resistant and Autumn Bean No. 1 and Qin-pi Bean were intermediate and considered tolerant. All other cultivars were considered susceptible.

Table 1. Data used to calculate the disease severity index and predicted values, September, Hubei Province

Year	Rainfall (mm) (x)	Rainy days (y)	Water integral index (ϕ)	Disease severity index calculated[a]	δ predicted
1973	173.6	22	3.64	4	4.90
1974	61.2	10	1.49	2	1.97
1975	84.7	10	1.71	2	2.18
1976	50.2	13	1.67	2	2.15
1977	127.9	12	2.28	3	2.76
1978	9.8	4	0.46	1	0.95
1979	52.1	12	1.59	2	2.08
1980				5	5.52

$r_{\delta\phi} = 0.988^{**}$, $r_{0.01,5} = 0.875$

Disease severity of annual forecast by the regression equation was:

$r = 0.49 + 0.009x + 0.093y$.

[a] 1 = below 20%, 2 = 21-40%, 3 = 41-60%, 4 = 61-80%, 5 = 81-100%.

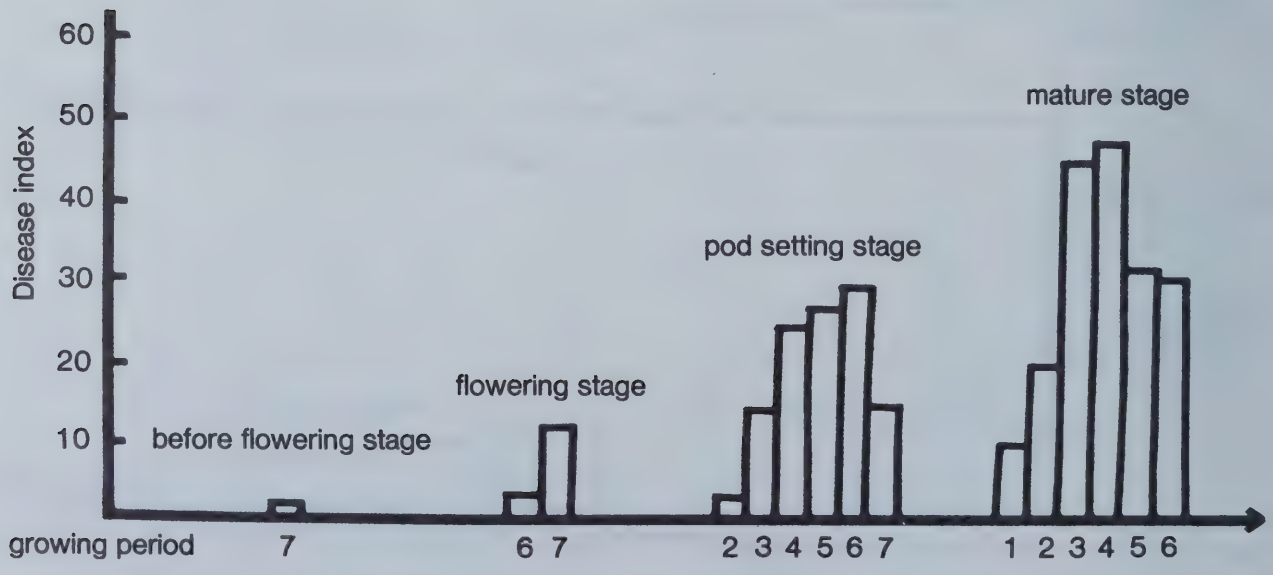

Figure 2. Relationship between disease severity and growth stages in experimental fields.

Table 2. Different resistance of cultivars, Xian-gan, Hubei, 1977

Cultivar	Disease rate (%)	Disease index	Source of cultivar
Jiu-Yue-wan	100	9.7	Zhejiang
Autumn Bean No. 1	100	21.1	Hunan
Qin-pi Bean	100	21.5	Jiangxi
Bao-luo Bean	100	30.0	Zhejiang
Hua-pi Bean	100	36.3	Zhejiang
Shunchang-yan-e-bao	100	36.7	Fujian
Hubei Bean No. 2	100	39.6	Hubei
Ta-qin Bean	100	40.1	Zhejiang
Hua-luo Bean	100	48.6	Jiangxi
Hou-zi-mao	100	50.0	Hubei

Table 3. Controlling effects of Bayton and Daconil in small plots

Fungicide	Concentration	Disease index[a]	Control effect (%)	Increasing yield rate (%)
20% Bayton	13 g/ml	16.7	82.1	68.2
75% Daconil	1:750	20.8	77.1	62.2
Control		99.3	0	

[a]Based on 0 to 6 where 0 = no uredea to 6 = leaf drop over two-thirds of the plant.

Chemical control. Plants sprayed with Bayton and Daconil in the experimental plots had higher yields than nonsprayed plants (Table 3). Bayton is a systemic fungicide with long-term effects and is the best fungicide for control of rust in the rainy season.

Under farmers' field conditions, phosphorylamide, whether sprayed one, two, or three times, gave 72% control with large increases in yield and 100-seed weights above the control (Table 4). The application of the fungicide at one, two, and three times increased the yield by 26.47%, 32.25%, and 76.00%; and 100-seed weight by 11.49%, 28.89%, and 40.02%, respectively. One spray of Daconil increased yield by 16.9% and 100-seed weight by 23.30%.

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Table 4. Test results of controlled phosphorylamide and Daconil in farm field

Fungicide	Spraying times	Area (ha)	Treatment	Disease index	Control effect	Yield kg/ha	Yield increase over control (%)	100 seeds weight (g)	100 seeds increase over control (%)
Phosphorylamide	1	2.2	Spray	18.09	72.42	967.5	26.47	14.35	11.49
			control	65.63		765.0		12.89	
	2	4.4	Spray	18.46	72.11	1,582.5	35.25	16.33	28.89
			control	66.83		1,170.0		12.67	
	3	3.7	Spray	18.55	72.99	1,177.5	76.00	17.04	40.02
			control	68.68		669.0		12.17	
Daconil	1	3.8	Spray	29.14	65.64	1,057.5	16.9	15.13	23.30
			control	84.80		907.5		12.27	

Determination of significance of disease index: phosphorylamide spray, one time: t = 2.20, 4.305 (t = 0.05); two times: t = 4.13, 3.49 (t = 0.01); three times: t = 4.14, 3.25 (t = 0.01). Daconil spray, one time: t = 2.78, 4.303 (t = 0.05).

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DISCUSSION

R. E. Ford asked if races of soybean rust were known in China.

Ma Yang Hong, in discussion with several delegate members, said that there was no evidence of races in China.

Wang Jin-ling asked if soybean rust occurs in the U.S.

R. E. Ford said that it had occurred in Georgia, probably in the 1920's, but is not now found there or in any other state in the U.S.; however, soybean rust is known to occur in Puerto Rico. He mentioned that environmental conditions in the U.S. are favorable for soybean rust.

G. R. Noel asked about the longevity of urediospores of *P. pachyrhizi*. The response by Yu Zi-lin was 61 days.

R. E. Ford asked if any alternate hosts for the soybean rust fungus were known in China. The answer was no.

H. E. Kauffman asked how extensive the screening program for resistance to soybean rust was in China.

Yu Zi-lin responded that there is no massive screening program but that resistance to rust has been determined for ten varieties commonly grown in regions where soybean rust occurs.

Dynamics of Aphid Transmission of Soybean Mosaic Virus

SUSAN E. HALBERT, MICHAEL E. IRWIN, AND ROBERT M. GOODMAN

Soybeans are susceptible to many viruses, but fewer than ten are of current economic importance. In addition to the viruses which occur throughout the world, there are some viruses which only occur in certain geographical regions. Soybean dwarf virus, for example, is very important in East Asia but has not been found elsewhere.

The most prevalent soybean virus is soybean mosaic virus (SMV). The disease caused by SMV was noted in the Western Hemisphere as early as 1916 by Clinton (1916), soon after serious scientific work began in North America to develop improved cultivars. While the worldwide spread of SMV is not documented, most of what is known about the virus and its epidemiology makes it likely that SMV was brought with the crop from China.

The physical and chemical properties of SMV are typical of potyviruses (Bos, 1972). The virus remains infective in plant sap for two to four days, has a dilution end point titer of about 10^{-3}, and a thermal inactivation point of less than 60°C. The virus is a moderately good antigen; rabbit antiserum titers of 1:2048 to 1:4096 have been reported (Ross, 1967).

SMV has a narrow experimental host range that, with the exception of two species in the genus *Chenopodium*, is confined to the legume family (Galvez, 1963). SMV is transmitted in the field and in the laboratory by aphids (Homoptera:Aphididae) in a nonpersistent manner and also is seed-transmitted in soybeans.

Seed transmission has resulted in worldwide distribution of SMV because soybean germplasm collections often are repositories of the virus (Cho and Goodman, 1979). International exchange of germplasm resources, necessary for continued improvement of the crop, carries a risk of further virus spread. However, the economic consequences of this situation have not yet been serious in the major soybean growing areas of the world.

That the virus can do damage, however, is beyond question. Published and unpublished reports of serious epidemics and yield loss caused by SMV in such diverse areas as Korea (Cho et al., 1977), Indonesia, Ecuador, the Soviet Union (Muraveva, 1973; Ovchinnikova, 1973), and Japan (Koshimizu and Iizuka, 1963) document the potential importance of the disease. The disease is widespread in the southern soybean growing areas of the U.S and in mixed infection with bean pod mottle virus can cause significant economic loss. Recent reports indicate that SMV is widespread and of concern in Brazil and in the People's Republic of China.

In studies on the pathogenic variation of seedborne SMV isolates recovered from the USDA germplasm collections, Cho and Goodman (1979) found that none of the soybean cultivars with resistance to SMV were resistant to all isolates of the virus. Severity of symptoms induced in susceptible cultivars and the virulence they displayed against SMV-resistant cultivars varied considerably among SMV isolates. Each source of SMV resistance currently in use provides useful protection to only a few of the SMV strains found in the germplasm collections. These results, together with the universal susceptibility of soybean cultivars commonly grown, suggest that SMV could become a major problem in soybean production.

Seed transmission in soybeans plays a pivotal role in the epidemiology of SMV. Seed transmission is the primary source of inoculum for field spread of SMV and is a major means of survival from season to season. Seed transmission also is the route by which the virus continues to be spread from one geographical region to another. The

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virus is not reported to be seed-transmitted in any of its other host plants, and is not often found naturally in species other than *Glycine max* and its close relatives.

Soybean seeds produced by SMV-infected plants exhibit a characteristic symptom termed mottling. Mottling is a discoloration of the seed coat of yellow-seeded soybeans caused by the "bleeding" of hilum pigment into other regions of the seed coat. Mottling also is influenced by environmental and genetic factors. Seed coat mottling is not a symptom of seed transmission, although in one report the incidence of seed transmission was twice as high for mottled seeds as for nonmottled seeds (Ross, 1968). There are soybean lines that show seed transmission but not mottling, others that show mottling but no or very low seed transmission, and many lines in which the incidence and severity of mottling vary significantly from one year to the next. Seed coat mottling, when it occurs, is an indication that the plant producing the seeds was probably infected, but nonmottled seeds from such plants may transmit and mottled seeds may not.

While not strictly related to SMV seed transmission, mottling is an important aspect of the impact of SMV on soybean seed quality, as the discoloration of the seed coat reduces the value of soybeans in commercial trade. Discolored seeds of whatever cause lead to lower value of the seeds, whether for food or planting the next crop. SMV infection also reduces the size of the seeds produced by infected plants. Seed size was reduced 10% to 20% in experiments conducted at UIUC.

The incidence of seed transmission of SMV in soybeans is affected by two principle factors: the time of infection in relation to plant development and the plant genotype. Seed transmission is reduced or eliminated when inoculation occurs during or after flowering (Bowers and Goodman, 1979; Irwin and Goodman, 1981). Thus, tactics that delay infection until after flowering will reduce the incidence of seed transmission. Another approach is to find genetic resistance to seed transmission. In an extensive recent study (Goodman and Oard, 1980) of this phenomenon, nearly 900 soybean germplasm accessions from temperate and tropical maturity groups were screened. Nineteen temperate lines and four tropical lines were found to have a low incidence of seed transmission. The incidence of transmission in the best tropical lines ranged from 0.05% to 0.2%. Since the incidence of seed transmission of SMV in improved cultivars is typically 5% to 20% when plants are inoculated before the onset of flowering, use of germplasm with lower rates of seed transmission offers the possibility of reducing primary inoculum levels by a factor of 10 or more. Among the tropical soybean accessions with low incidence of seed transmission, Improved Pelican and UFV-1 are two named cultivars with superior agronomic qualities.

SMV-infected seedlings are often less vigorous than noninfected siblings. In the field, the less vigorous seedlings from a seed lot with a low incidence of seed transmission lose out in the competition for canopy space and are shaded out by more vigorous, healthy plants nearby. Thus in a season or location where early-season spread of the virus does not occur, the consequences of an occasional SMV-infected plant in a seed lot may be negligible.

One of the epidemiological questions that has not been answered is at what level seed transmission of SMV becomes significant. Because soybeans, like other legumes, can compensate when neighboring plants are removed during vegetative growth, severely infected seedlings that are eliminated during the vegetative development of the crop probably could be tolerated at quite high incidence with no loss of yield as long as SMV does not spread to healthy plants. Seedlings that are virus-infected but are relatively vigorous may result in greater losses, both because they extend the time during which they may serve as sources of inoculum for spread by aphids, and because they take up space in the canopy but have less potential for seed production. This question is one that will have to be answered by a series of carefully controlled field studies with a variety of SMV strains and soybean cultivars and in a variety of environments.

There are conflicting reports in the literature about the impact of SMV infection on germination of soybean seeds. Recent evidence shows that reduced germination of seeds from SMV-infected plants may be caused by infection by *Phomopsis sojae*, the pod and stem blight pathogen (Hepperly et al., 1979). Some, but not all, soybean cultivars investigated showed a predisposition to *P. sojae* infection as a consequence of SMV infection, and some cultivars ordinarily resistant to infection by *P. sojae* became susceptible to the fungus when the plants were SMV-infected. The ability of seedborne *P. sojae* to reduce germination of soybean seeds is well established, and results from controlled inoculation experiments showed that it was the seedborne fungus rather than virus infection that reduced germination in seed lots from SMV-infected plants. There

is no evidence linking embryo infection by SMV with reduced germination.

SMV is transmitted from plant to plant within the field by members of the family Aphididae (Insecta:Homoptera). Laboratory tests confirm the nonpersistent manner by which SMV is transmitted; using laboratory-reared clones of apterous *Myzus persicae* (Sulzer), we demonstrated optimum transmission from acquisition probes of 30 to 60 seconds (Schultz et al., submitted manuscript; Irwin and Schultz, 1981).

In Asia and parts of Africa, three species of aphids colonize soybean fields, but aphids seldom colonize soybean fields in the rest of the world. However, *Aphis craccivora* Koch can form small temporary colonies on soybeans in the high jungles of Peru (Irwin and Goodman, 1981).

The timing and rate of SMV spread in a soybean field is, to a large extent, a function of the activity of transient aphids that land on soybean leaves, probe, move to new plants, and probe again. We developed a technique to trap and assay aphid alatae for incidence of SMV transmission among naturally occurring transient aphid populations downwind of a field of infected soybeans (Halbert et. al, 1981). In a two-year study in central Illinois, 1,709 alate aphids were trapped alive and assayed, 4.2% of which transmitted SMV. Five species of aphids accounted for more than 93% of the transmissions: *A. craccivora*, *Macrosiphum euphorbiae* (Thomas), *M. persicae*, *Rhopalosiphum maidis* (Fitch), and *Rhopalosiphum padi* (L.). At least 55 additional species were assayed, five of which transmitted only once. Others did not transmit.

Because virus infection during the earlier growth stages of soybeans increases the loss of yield and the percentage of seed-borne virus more than infection of more mature plants, vector species that tend to fly in mid- to late spring are most important in the spread of SMV. *R. maidis* flew in mid- to late summer and autumn. *R. padi* was not abundant at any time of year and its transmission efficiency was low. *M. persicae* tended to fly in mid-summer. *A. craccivora* and *M. euphorbiae*, which had major flights in late spring and early summer and relatively high transmission efficiencies, are potentially important in the spread of SMV in central Illinois. A third species, *Aphis citricola* Van der Goot, also may be important because it flies in late spring, and laboratory data suggest it is an efficient vector of SMV. *A. citricola* was not assayed by our technique because we trapped in the morning, and this species appears to fly later in the day (Halbert et. al, 1981).

Field experiments conducted in Urbana, Illinois, in 1977-1980 suggest that a number of environmental factors modify landing rates of some species of aphid alatae (Halbert and Irwin, 1981; M.E. Irwin and G. A. Schultz, unpublished data). The factors include percentage of ground cover, planting date, canopy color, and type of crop. Six aphid species were consistently present in sufficient numbers to allow comparisons of most factors: *A. citricola*, *Capitophorus elaeagni* (del Guercio), *M. euphorbiae*, *Myzocallis punctatus* (Monell), *R. maidis*, and *Therioaphis trifolii* (Monell). More *A. citricola* were trapped in denser ground cover than in areas with a lower percentage of ground cover. However, in another experiment, fewer were trapped in earlier plantings of soybeans than in later-planted soybeans. *R. maidis* showed no change in landings in soybeans with differences in ground cover but were trapped more abundantly in later-planted soybeans. *C. elaeagni* also were more abundant in later-planted soybeans and in plots with a lower percentage of ground cover. Landing rates of *M. punctatus* were not altered by differences in planting date, but denser ground cover elicited more landings.

The factors that elicit landing are complex and differ among species. A closer examination of these factors might reveal methods for slowing and delaying virus epidemics in cropping systems. In the ground cover experiment, one major variable was involved whereas there were two variables in the planting date experiment: ground cover and plant age. Canopy color (yellow-green or dark green) either had no effect on landing rates (*M. punctatus*, *T. trifolii*) or the dark green increased landing rates over the yellow-green (*M. euphorbiae*, *R. maidis*) (Irwin and Goodman, 1981). When landing rates in maize and soybean plots were compared, either there was no difference (*C. elaeagni*, *R. maidis*) or more were trapped over soybeans (*M. euphorbiae*, *M. punctatus*, *T. trifolii*) than maize (M. E. Irwin, unpublished data).

In an effort to understand which aphid species were responsible for spread of SMV in the Nanjing area, landing alate aphids were trapped from May 6 to September 19, 1981, in a soybean field at the Nanjing Agricultural College using green pan traps (Irwin, 1980). Numerous *M. persicae* and *Lipaphis erysimi* (Kaltenbach) in trap collections adequately account for virus transmission during May. *Eriosoma* sp. also was abundant at that time, but they probably are not an important vector since *Eriosoma* spp. are rarely implicated in virus transmission.

SMV also spreads actively among summer soybeans in mid-August in the Nanjing area (Pu Zu-qin, personal communication). It was assumed that the soybean aphid *Aphis glycines* Matsumura was responsible; however, the results indicate that transient *Aphis citricola* Glover were much more important vectors in Nanjing in 1981.

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DISCUSSION

S. M. Lim asked if yield reductions caused by date of planting and SMV could be separated.

M. E. Irwin reported that R. L. Bernard recently said that there is no accurate way of separating the impact of these two factors.

M. E. Irwin mentioned that seed transmission is the primary source of inoculum for field spread of SMV in the U.S. and questioned the Chinese delegation as to whether this is true in China. Apparently, this is the case in China.

S. E. Halbert mentioned that in China aphids have been reported to colonize soybean fields but in the U.S. they are transient in nature.

M. E. Irwin added that SMV spread in soybeans is based on the activity of transient aphids that land on leaves, probe, and move to new plants and probe again. A spread of 50 meters can take place in a soybean field in one season, and this spread takes place downwind of a field of infected soybeans.

D. M. Daugherty asked about the persistency of SMV in aphids.

M. E. Irwin answered that SMV is transmitted by aphids in a nonpersistent manner. Optimum transmission of SMV occurs from acquisition probes by aphids of 30-60 seconds. Thirty minutes after acquisition, aphids can no longer infect soybean plants.

R. L. Bernard asked if vectors other than aphids transmit SMV and if all aphids are capable of transmitting the virus.

M. E. Irwin and S. E. Halbert responded that other than aphids, only humans can transmit the virus; and that there are some aphid species that are not capable of transmitting the virus.

R. M. Goodman said that if aphids do not move they do not transmit SMV. He added that SMV is not likely to be transmitted by walking through soybean fields or by ordinary handling of plants.

S. M. Lim asked which plays a more important role in the epidemiology of SMV, seed transmission or aphid vectors.

M. E. Irwin indicated that both are important.

On control of SMV, S. M. Lim asked if the elimination of infected seed would reduce the initial infection.

M. E. Irwin said yes and added that because SMV is transmitted by transient aphids, insecticidal control of the aphid vectors is not a practical solution.

R. M. Goodman stated that elimination of the inoculum source is the key factor in controlling SMV. He added that the level of resistance in soybean cultivars is not good.

Ma Rhu-hwa and Wang Jin-ling mentioned that virus diseases of soybeans are important in China and scientists are studying virus diseases. They expressed their desire to discuss virus diseases more in depth during the 1983 China/USA Soybean Symposium.

Cooperation in Soybean Entomology

MARCOS KOGAN

The University of Illinois at Urbana-Champaign and its allied institution, the Illinois Natural History Survey, have a broadly based program in soybean entomology. Over the years, this program has developed strong interactions with other programs within the U.S. through the development of collaborative projects. We have maintained also a strong interest in international activities and have developed cooperative programs in South America and the Orient.

Looking at the various soybean production areas of the world, we can identify different agricultural ecosystems. For example, in midwestern U.S. the typical agroecosystem is a maize-soybean system with patches of permanent woodlots and occasional patches of forage crops, particularly alfalfa. Double cropping with wheat is introducing additional diversity in the midwestern agroecosystems. In the Orient, agroecosystems are more diverse through the practices of intercropping and multiple cropping with a large variety of other crops growing together or in succession with soybeans.

Differences in agroecosystem composition and complexity directly affect the pest composition and intensity of pest problems. We have made attempts to collect data from many soybean ecosystems throughout the world. These data are being assembled in a synoptic collection of soybean arthropods. Based on the data collected and also on published information, we have made some comparative analyses and have come to the conclusion that in the areas of the world where soybeans have been introduced recently or where the crop is expanding, there is a dynamic process of adaptation of insect pests to the crop. Adaptive shifts seem to occur in contemporary time leading native species to better exploit available resources. We have observed also that pest management tactics may have an impact on the rates and directions of these adaptive shifts, and they should be a major concern in integrated pest management programs.

Integrated pest management (IPM) is defined as the selection of practices that will assure favorable economic, environmental, and social consequences through the use of appropriate cultural, biological, and chemical control measures.

With the advantage of having visited the major soybean producing areas in the People's Republic of China in 1981, I would like to discuss some fundamental components of IPM programs for soybeans that I believe offer excellent opportunities for the development of collaborative programs between the People's Republic of China and the U.S. The following summary of the main areas may serve as a basis for future discussions.

The key pests of soybeans in the Orient are pod borers and the soybean aphid. These pests are not known to occur in the western hemisphere. However, well-adapted legume feeders such as the bean leaf beetles (*Cerotoma* spp.) and the Mexican bean beetle (*Epilachna varivestis*), as well as certain species of stink bugs of the American continent, do not occur in China. The recent history of invasions of new areas by exotic pests shows that such pests are difficult to detect by regular quarantine procedures, and are difficult, if not impossible, to eradicate once they become established. It is therefore extremely important to build a background of knowledge on these pests before they are transferred from one region to the next. Joint programs in the studies of some of these pests would be of great benefit.

FOUNDATIONS OF IPM PROGRAMS

Sampling Techniques with Emphasis On Development of Sequential Sampling Plans

Sampling is the foremost tool both in basic ecological studies of animal populations and in the development of IPM programs and decision-making. Great progress has been achieved in the U.S. on the improvement

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of sampling techniques and the development of sequential sampling plans for pests, natural enemies, and damage levels. Such techniques should be locally tested if they are to be applied in other parts of the world. The experience accumulated in this area can be made available through exchange channels with the People's Republic of China.

Definition of Economic Injury Levels

It is impossible to implement an effective pest management program without a definition of economic thresholds for the major pests. It is becoming increasingly apparent that a better understanding must be achieved of the impact of pest complexes. A body of experimental procedures now is available to test economic thresholds for defoliating insect pests, pod-feeding pests, and some of the interactions, particularly with weed competition and plant pathogens. There is much interest, and great difficulty, in defining economic thresholds for pests with sucking mouth parts such as the soybean aphid. Work in this area should help both China and the U.S. in the definition of these thresholds.

Development of Forecasting and Predictive Models

Great advances have been made in the use of systems analysis in the description of the complex interactions that exist between the crop and the pests, particularly with regard to insect populations. Models now are available that describe the crop growth. Superimposed on these models and coupled with them are models that describe the population dynamics of several insect pests as they are affected by weather and natural enemies. One of these models was developed in Illinois for the bean leaf beetle, and it is helping us to forecast outbreaks. The technology that is accumulating is potentially useful for other pests. It may be useful for the pod borer as this univoltine pest may be modeled using biological information that is available. Development of such a model would help the design of pest management programs.

CONTROL TACTICS

Host Plant Resistance

The main emphasis in the breeding programs in the U.S. has been breeding for resistance to defoliating pests. Three PI's have been identified as sources of resistance to defoliators: PI 171451, 227687, and 229358. A breeding program was started at UIUC in 1971. In 1981 it produced advanced lines with some levels of resistance and good agronomic characteristics. Five of these lines were released for public use. Screening programs also are underway for stink bug resistance, and we have initiated a screening program in Puerto Rico for resistance to certain stem- and pod-feeding pests. These breeding materials are available for evaluation under other conditions.

We have worked to improve screening and evaluation techniques for breeding lines. In addition, we have been very much involved in investigations on the mechanisms of resistance to defoliators. Advances have been made in the understanding of the chemistry of resistance in some of these lines.

There is a great need to evaluate new agronomic lines for insect resistance. There has been a tendency by breeders to spray their nurseries for insect control, thus eliminating any possibility of evaluating new cultivars before they are released. There is a need to establish criteria for evaluation of new cultivars prior to their release by submitting them to normal insect pressures.

Biological Control

We have made an effort to evaluate the action of natural control agents of pests in our soybean ecosystems and to define the impact of other control tactics on the effectiveness of natural enemies of pests. Work has been done on the effect of chemical control on the resurgence of pest populations, on the interactions between cultural control and natural enemies, and interactions of plant resistance and natural enemies.

Recent work has led to the identification of new sources of biological control agents in South America and in the Orient. Of particular importance were parasites of stink bugs, *Heliothis*, and loopers. Also, promising pathogens of several lepidopterous larvae have been collected. Some of these natural enemies currently are kept under laboratory conditions and are available for exchanges. We have had an opportunity to survey and collect a few natural enemies of soybean pests in China and are proposing an extension of this collaborative program. In China there may be potentially useful natural enemies of stink bugs for the U.S., and China may benefit from the importation of certain types of insect pathogens, particularly nuclear polyhedrosis viruses of *Heliothis* and loopers.

Cultural Controls

Cultural practices have a direct impact on insect pests and natural enemies. Research is under way to determine the long-term effects of changing cultural practices, such as minimum tillage, crop rotation, and intercropping, on the insect community. The technique known as trap cropping has been employed in certain areas. Traps are strips of attractive plants on which pests are concentrated and treated. A trap-cropping plan has been proposed for the control of soybean pod borers in Korea. Given the biological characteristics of the soybean pod borer, using strips of plants whose maturity coincides with the emergence of the pod borer would have a potential for use in IPM programs for this pest.

Chemical Control

Any IPM system is not complete without a definition of the roles of insecticides in the program. This definition should be made on the basis of minimum effective rates to achieve control of the pest with the least impact on the beneficial parasites and predators. This is the key for integration of biological control with chemical control. Additional screening for new and more effective insecticides should be made not only on the target species but also on their natural enemies. As part of a chemical control program, potential shifts in the status of resistance in the natural pest populations should be monitored.

Integrated Pest Management

When implemented, IPM programs should reduce the cost of application of insecticides and the undesirable side effects of programs that rely solely on insecticide use for pest control. I saw examples of successful IPM programs in China for the pod borer on soybeans. Integrated programs represent an area of interest to both China and the U.S., and this is the area in which much progress can be achieved by combining efforts and exchanging experiences and information.

EXCHANGE OF INFORMATION

During the last 12 years Illinois has made a major effort to develop a comprehensive data base for information on soybean entomology through SIRIC, the Soybean Insect Research Information Center, and ISIC, the International Soybean Insect Collection. SIRIC is devoted to the search and retrieval of the published literature on soybean entomology and ISIC to identification of arthropods associated with soybeans in the world. Both data bases are computerized and represent a resource available to cooperators throughout the world.

SIRIC made one of the first overtures to establish contact with soybean researchers in the People's Republic of China soon after the reestablishment of relations between the two countries in 1976. A letter was sent to the major institutions in China to identify sources of literature. As a result we now receive and exchange publications with several major research institutions in China.

Through the exchange of visiting scholars, graduate students, and scientific delegations, we hope to maintain an active program in soybean entomology with the People's Republic of China. If we are to credit several estimates that have been made in many parts of the world, a yearly loss of 10% to 30% is due to the impact of insect pests. By developing sound IPM programs one may expect to substantially reduce the economic impact of these pests.

DISCUSSION

Wang Jin-ling stated that approximately $4,000,000 was spent in Heilongjiang Province to control a borer which is normally not destructive. Lights were turned on in one village during the night, apparently in an attempt to attract the insects.

Zhang Zi-jin stated that there are ten major insect pests of soybeans and soybean aphids are the most important. Soybean pod borers also are important. Control is effected with resistant cultivars such as Jilin 3, 4, 33, and 13. Chemical control and biological control also are practiced.

R. L. Bernard asked what control methods are used for soybean aphids and if there are resistant cultivars.

Zhang Zi-jin replied that there are resistant cultivars. An example is Big White Eyebrows, which has a high level of resistance to aphids. A discussion concerning the mechanism of resistance then took place. Resistance to aphids may be due to the leaves being coarse and rough with more pubescence. This cultivar is indeterminate. There is also a determinate cultivar which is resistant and has a thick leaf.

S. E. Halbert noticed two species of aphids colonizing soybeans during her visit to PRC and wondered if Zhang was breeding for resistance to those two species.

Zhang Zi-jin replied that they are just beginning their research and do not fully understand the biology of these aphids.

G. Kampmeier asked how often aphid-resistant cultivars are planted in the PRC.

Again, the reply was that they are just beginning to work.

The question was asked about how often alates are formed on PRC cultivars. The answer was that there may be 15 generations of nonalate aphids formed during the season. Alates may be formed only on winter hosts. However, S. E. Halbert stated that she saw alates during July.

R. L. Bernard asked if chemical control is used for aphids.

Wang Jin-ling replied that at the moment the most efficient method of control is chemical control, and the Chinese use Cygon (dimethoate) with low-volume applications.

LEFT TO RIGHT: Jin Xin-min, Visiting Scholar, University of Minnesota; Yang Hong, Interpreter; Sun Huan, Visiting Scholar, Iowa State University; Wu Yi-kang, Counselor for Science and Technology, Embassy of People's Republic of China, Washington, D.C.; Fang Ping, Visiting Scholar, Iowa State University, Wang Jin-ling, Head of Delegation, Professor, Northeast China Agricultural College; Thomas F. Kelly, Program Leader/People's Republic of China, Office of International Cooperation and Development, U.S. Department of Agriculture; Orville G. Bentley, Dean, College of Agriculture, University of Illinois at Urbana-Champaign; Ma Rhu-hwa, Deputy Head of Delegation, Professor, Nanjing Agricultural College; Shen Yin-pu, Second Secretary of Science and Technology, Embassy of People's Republic of China, Washington, D.C.; Chen Yong-xuan, Visiting Scholar, Rutgers University, New Brunswick, New Jersey; Dong Zhenda, Deputy Director of Soybean Research Institute, Academy of Agricultural Reclamation of Heilongjiang Province; Yu Zi-lin, Assistant Research Fellow, Oil Crops Research Institute, Academy of Agricultural Sciences; Guo Xiang-ao, Associate Professor, Zhengzhao Grain College; Zhang Zi-jin, Deputy Director, Soybean Research Institute, Jilin Academy of Agricultural Sciences; Zhang Rong-xian, Visiting Scholar, Brigham Young University, Provo, Utah; Qu Ning-kang, Secretary of Delegation, Deputy Chief of Division of Science and Technology Exchanges, Bureau of Science and Technology, Ministry of Agriculture, Animal Husbandry and Fishery; Gai Jun-yi, Visiting Scholar, Iowa State University.

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